ACRP

REPORT 67

AIRPORT
COOPERATIVE
RESEARCH
PROGRAM

Sponsored by
the Federal
Aviation
Administration

Airport Passenger Conveyance Systems Planning Guidebook

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP REPORT 67

Airport Passenger Conveyance Systems Planning Guidebook

TransSolutions, LLC
Fort Worth, TX

Clemson University
Clemson, SC

Kimley-Horn and Associates, Inc.
San Antonio, TX

Subscriber Categories
Administration and Management • Aviation • Design

Research sponsored by the Federal Aviation Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2012
www.TRB.org

AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

The need for ACRP was identified in *TRB Special Report 272: Airport Research Needs: Cooperative Solutions* in 2003, based on a study sponsored by the Federal Aviation Administration (FAA). The ACRP carries out applied research on problems that are shared by airport operating agencies and are not being adequately addressed by existing federal research programs. It is modeled after the successful National Cooperative Highway Research Program and Transit Cooperative Research Program. The ACRP undertakes research and other technical activities in a variety of airport subject areas, including design, construction, maintenance, operations, safety, security, policy, planning, human resources, and administration. The ACRP provides a forum where airport operators can cooperatively address common operational problems.

The ACRP was authorized in December 2003 as part of the Vision 100-Century of Aviation Reauthorization Act. The primary participants in the ACRP are (1) an independent governing board, the ACRP Oversight Committee (AOC), appointed by the Secretary of the U.S. Department of Transportation with representation from airport operating agencies, other stakeholders, and relevant industry organizations such as the Airports Council International-North America (ACI-NA), the American Association of Airport Executives (AAAE), the National Association of State Aviation Officials (NASAO), Airlines for America (A4A), and the Airport Consultants Council (ACC) as vital links to the airport community; (2) the TRB as program manager and secretariat for the governing board; and (3) the FAA as program sponsor. In October 2005, the FAA executed a contract with the National Academies formally initiating the program.

The ACRP benefits from the cooperation and participation of airport professionals, air carriers, shippers, state and local government officials, equipment and service suppliers, other airport users, and research organizations. Each of these participants has different interests and responsibilities, and each is an integral part of this cooperative research effort.

Research problem statements for the ACRP are solicited periodically but may be submitted to the TRB by anyone at any time. It is the responsibility of the AOC to formulate the research program by identifying the highest priority projects and defining funding levels and expected products.

Once selected, each ACRP project is assigned to an expert panel, appointed by the TRB. Panels include experienced practitioners and research specialists; heavy emphasis is placed on including airport professionals, the intended users of the research products. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, ACRP project panels serve voluntarily without compensation.

Primary emphasis is placed on disseminating ACRP results to the intended end-users of the research: airport operating agencies, service providers, and suppliers. The ACRP produces a series of research reports for use by airport operators, local agencies, the FAA, and other interested parties, and industry associations may arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by airport-industry practitioners.

ACRP REPORT 67

Project 03-14
ISSN 1935-9802
ISBN 978-0-309-21412-4
Library of Congress Control Number 2012938553

Published reports of the

AIRPORT COOPERATIVE RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at

http://www.national-academies.org/trb/bookstore

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

FOREWORD

By Lawrence D. Goldstein
Staff Officer
Transportation Research Board

ACRP Report 67 provides a Guidebook for planning and implementing passenger conveyance systems at airports based on actual case study analysis of how these components function in real-time situations. It describes best practices and specific design considerations and presents decision-making frameworks for implementing passenger conveyance systems. Passenger conveyance components include escalators, elevators, moving walkways, and passenger assist vehicles/carts. Automated People Mover systems (the subject of *ACRP Reports 37* and *37A*), personal rapid transit systems, and shuttle bus systems are not covered in the Guidebook.

In addition to the Guidebook, *ACRP Report 67* also includes a comprehensive database along with a Decision-Support Tool for planning, designing, and evaluating passenger conveyance systems at airports as a function of specific airport design and operating parameters. This database allows project planners to examine how passenger conveyance components operate as a system throughout different areas within the airport environment.

The Guidebook is directed primarily at airport planners, passenger terminal planners, and architects. Along with the accompanying database, it provides estimates of actual throughputs and capacities based on what is actually being achieved in airport operations.

With growth of air traffic and passenger demand, capacity will continue to be an issue at existing, expanding, and new airport facilities. In addition, the cost of new construction continues to increase in the context of diminishing funds, placing a premium on optimization of existing space and planning of new facilities. Peak-period demand accommodating both origin and destination flights as well as connections creates complex terminal design requirements affecting passenger circulation through all areas of an airport. A critical factor affecting passenger circulation is the capacity of individual passenger conveyance facilities.

Passenger walk distance and ease of use must be considered when passenger terminal facilities are planned, especially in light of changing demographics, increasing capacity and demand, and travel distances within the airport. In all airports, elevators and escalators are used to ease passenger vertical transitions, while moving walkways, passenger assist vehicles, and wheelchairs are often included to reduce walking distance and speed transit through an airport. Interaction of these various components as part of the overall conveyance system within and through the terminal is complex. Also, how efficiently the system works as a function of terminal design influences passenger flow through the facility which, in turn, affects overall customer satisfaction. In some cases, even though passenger conveyance systems are provided, a certain percentage of passengers will still choose to walk beside the moving walkway, walk while on the moving walkway, or take stairs instead of elevators or escalators. To estimate space requirements for passenger conveyance systems, airport

planners and designers must consider passenger choice of walking versus riding and be able to incorporate actual conditions into system planning considerations. Personal choice is affected by the queue length to access the conveyance system (balking will occur if the queue is too long), congestion on the system limiting ability to pass, and perceived length and difficulty of the walk. Other issues to consider include new and emerging technologies such as high-speed and accelerating moving walkways and ability of older passengers to navigate them.

Conveyance systems all have design capacities, yet these measures have not always reflected actual throughput that can practically be achieved in an airport environment. This Guidebook and the supporting database provide necessary tools and techniques for planning efficient, realistic passenger flow as part of the larger terminal planning process.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

CHAPTER 1

Background

1.1 Introduction

In recent years, airports are challenged with providing good passenger experience under constrained budgets. Decisions on capital improvement programs and asset management require good data to guide expenditures of limited funding. Meanwhile, to meet increasing passenger demand, airports and airport terminal facilities are becoming larger. For example, the introduction of the Airbus A380 has posed new requirements in terminal planning (Pfurr 2006). However, with the economic downturn at the end of the decade, some of these plans have changed, but load factors on airplanes have continued to increase—also shaping the needs of an airport terminal.

Further, as the population ages, a sharper focus has been put on accommodating these passengers and facilitating their travel through the terminal. Airports have begun to add facilities to help these passengers easily traverse the terminal area.

In general, planners, designers, and operators of airports face substantial challenges in how to move their passengers faster and more efficiently. To achieve acceptable passenger walking distances, aircraft-to-aircraft transfer times, and overall transit times in terminals, several passenger mobility technologies are commonly used. These technologies include moving walkways, passenger assist vehicles, buses between terminals and parking areas, and automated people movers (APMs). Moving walkways provide a more efficient means of traveling horizontally through terminal areas by allowing passengers to travel on moving plates that comprise the moving walkways, resulting in reduced travel times through the terminals. Passenger assist vehicles, or carts, serve an important role in helping passengers needing special assistance and offer flexibility because they are maneuverable and do not require an exclusive right-of-way. However, carts can be less desirable because they operate in mixed traffic with pedestrians. The specific focus of this Guidebook is to provide a framework to evaluate the following passenger conveyance systems: moving walkways, escalators, and elevators. Although APMs and buses do not qualify as passenger conveyance options within the scope of this Guidebook, these transport modes are mentioned because they are integral to the overall movement of passengers through airports.

In support of this Guidebook, a literature review was conducted of five main categories: passenger conveyance planning, pedestrian behavior and walking distance, level of service of pedestrian facilities, passenger conveyance systems, and capacity of conveyance systems. Pertinent information obtained from this literature review regarding the best practices, operations, maintenance considerations, and physical characteristics of moving sidewalks, escalators, and elevators are summarized in this Guidebook. The effect of passenger characteristics on the choice of passenger conveyance is also discussed.

In addition to the literature review, a data collection effort was undertaken to document actual passenger behavior and passenger conveyance choices. The value of being able to assess

pedestrian behavior based on actual data in real systems cannot be overemphasized. To observe the actual in-airport conditions, data was collected at five North American airports in order to complement the study information obtained from the literature review with actual site-specific data points. Over 237,000 data points were collected, summarized, and analyzed and then populated into a database. Directions on how to download, access, and use this database are provided in this Guidebook in Chapter 5.

An existing set of industry safety standards and maintenance personnel certification guidelines for the equipment are discussed in this planning-oriented Guidebook. Of particular importance in this set of industry documents is American Society of Mechanical Engineers (ASME) A17.1—2010/Canadian Standards Association (CSA) B44—10 Safety Code for Elevators and Escalators. This safety "Code" also addresses moving walkways and freight elevators and should be considered a relevant reference document. Throughout this Guidebook, this safety code is referred to as "ASME A17.1." Other documents concerning elevators, escalators, and moving walkways are also provided by ASME under the A17 series.

1.2 Purpose of Guidebook

The purpose of this Guidebook is to provide a decision-support tool for planning, designing, and evaluating passenger conveyance systems at airports. In support of this objective, the Guidebook has the following components:

- Design considerations for including passenger conveyance systems in an airport environment
- A decision-making framework with user instructions, that includes
  - Checklist for planning, design, selection, and feasibility of specific passenger conveyance components at an airport
  - Key steps for implementing a passenger conveyance system
  - Requirements for implementing, operating and maintaining the passenger conveyance system
- Best practices for various types of passenger conveyance systems

As mentioned, this Guidebook will not consider APMs—another Airport Cooperative Research project and corresponding Guidebook, *ACRP Report 37: Guidebook for Planning and Implementing Automated People Mover Systems at Airports,* has developed and summarized the planning guidelines specific to APMs.

The benefit of this Guidebook to the aviation community is that it develops a set of current that can be used by planners, architects, and engineers. This Guidebook, in association with its decision-making framework and the supporting database, will assist airport planners and operators when considering conveyances to facilitate the movement of passengers and reduce walking/transit times through airports. This improved planning process will result in more efficient passenger transit with a positive passenger experience at North American airports.

1.3 Data Collection Locations

Data was collected at five medium to large airports in 2009. The airports studied were Hartsfield-Jackson Atlanta International Airport (ATL), Charlotte/Douglas International Airport (CLT), Dallas-Fort Worth International Airport (DFW), Denver International Airport (DEN), and Orlando International Airport (MCO).

CHAPTER 2

Best Practices

Passenger conveyance systems in the airport environment, although similar to uses in other facilities, are unique in that they must address the implications of surge demand levels, interactions between floor plates of terminal facilities, the nuances of sterile and non-sterile environments, and the oftentimes 24-7 operational requirements placed on each of the components. For these reasons, it is critical to understand the baseline planning assumptions and established design guidelines for the application of these passenger conveyance systems. These guidelines and assumptions include understanding and applying varying capacities/levels-of-service, determining space requirements for the various components, and fully understanding the implications of lifecycle costs with these systems.

2.1 Moving Walkway

When discussing optimal passenger terminal building configurations, de Neufville et al. (2002) mention that moving walkways are a relatively inexpensive means to move people through an airport. The conventional moving walkway is a pedestrian-carrying device where passengers may stand or walk. In a comparison study, Leder (1991) reviews advantages, disadvantages, and limitations of four airport terminal passenger mobility systems: moving walkways, electric passenger carts, buses, and APMs. In this article, the author suggests that moving walkways can be used to aid passenger mobility when the total distance of passenger movement does not exceed 1,000 to 1,500 feet, and when point-to-point travel along a straight line is acceptable (or allowable). On the contrary, APMs are best suited for route lengths in excess of 1,000 feet and with relatively high ridership.

2.1.1 Physical Characteristics

Several fundamental physical characteristics should be understood and planned for by the designer. These characteristics include speed performance, angle/maximum rise/maximum length, step width, and provided queue areas. Each of these affects system performance and the ability to satisfy peak demands at airports.

Table 2-1 shows system characteristics for moving walkways researched, by manufacturer. The information summarized in the table is from readily available industry product information. Special design features are very common and the manufacturer should be consulted if conditions such as longer lengths are desirable.

Additional information on the individual physical characteristics is provided in the following sections.

Table 2-1. Moving walkway characteristics.

Manufacturer	Product/ Model	Max Speed (fpm)	Pallet Width (in)	Maximum Length (ft)	Max Angle of Inclination (if available)
ThyssenKrupp	Orinoco	100-125	32-64	656	12°
Stannah	ST	**	32-55	440	10°-12°
Fujitec	GS8000	98	32-40	164	12°
Schindler	9500	**	32-40	328	12°
Otis	NCT	**	32-40	263	**
	NPT	**	40-56	394	**
Kone	Autowalk Stanchion	100-130	32-56	**	3°
	Autowalk Truss	100-130	40-56	**	3°

** - information not available

NOTE: This information represents a sampling of product data from manufacturer's websites. Additional information is available directly from the equipment manufacturers.

2.1.1.1 Operating Speed

As illustrated in Table 2-1, maximum speeds of the moving walkway systems researched range between 98 and 130 feet per minute (fpm). The main reason for the limitation in operating speed is due to safety concerns of passengers as they board and exit. Furthermore, the speeds of most moving walkways are adjustable and the actual operating speed may be a matter of consideration, in consultation with the operations staff at the individual airport. A higher speed moving walkway by ThyssenKrupp has been installed at Toronto Pearson International Airport. Over 900 feet long, the walkway operates at approximately 440 fpm for most of the length, with a speed closer to 110 fpm at the beginning and the end of the walkway. This walkway is a pallet-type in which the pallets "intermesh" with a comb and slot arrangement. They expand out of each other when speeding up, and compress into each other when slowing down, with the handrails working in a similar manner.

2.1.1.2 Angle/Maximum Rise/Maximum Length

Maximum length ranges from 164 to 656 feet, but a practical maximum length is around 300 feet per unit. Certain systems can be constructed with an incline. The limitation of the maximum inclination angle defined by ASME A17.1 (Section 6.2.3.1) is 3 degrees within 36 inches of the entry and exit ends, and no more than 12 degrees at any point.

2.1.1.3 Step Width

Step widths for these systems ranged from 32 to 64 inches. In airport applications the narrow widths can be problematic, especially with roll-a-board luggage now commonly accompanying many passengers. In particular, the frustration of someone who wants to walk on a moving walkway while others want to stand is mitigated by the wider step widths which can allow people to pass one another, even with luggage. The costs and building design provisions for the larger step width, however, and the implications for the overall width of the entire pedestrian corridor work against the choice of the wider step widths.

The final determination of preferred step width is a design decision that should include the consideration of passenger demand levels, the length of the travel on the moving walkway, the building design parameters affected by the width of the unit and all the associated the costs. So the decisions on moving walkway step widths are best made through a consensus process, with

the assessment group including the architect, the terminal functional/space planners, airport operations staff, and other key stakeholders who would be concerned with passenger service perceptions.

2.1.1.4 Queue Areas

That escalators and moving walkways can generate large queues, even at traffic levels below the capacity of the unit is often overlooked by designers. Queuing is often generated by peak surges of passengers in an airport environment. As a result, designers must often analyze the peak 10- to 15-minute period to account for pedestrian surges on conveyance devices. Assessments of baggage quantities should also be estimated, because this will affect space requirements per person and per party. Typical area queues range from 13 square feet per person (sfpp) to as much as 17 sfpp. If programmed properly, this translates into standard queue platforms of between 15 and 30 feet in depth, depending on the passenger surge, while the width of the queue mirrors the conveyance device width.

The absolute minimum of clear area at the entry and exit zones of moving walkways is defined in ASME A17.1 (Section 6.2.3.8.4) as twice the distance between the centerlines of the handrails. As a practical planning rule, if multiple moving walkways are operating in a serial configuration, this safety zone must be provided independently for each moving walkway. Further, the provision of suitable queuing area at the entrance to the moving walkway and in the safety zone at the exiting end must consider the effects of all pedestrian traffic passing through the area, whether or not the pedestrians are using the moving walkway system.

2.1.1.5 Equipment Design Considerations

When designing moving walkways, specific focused attention needs to be paid to the equipment storage and spacing requirements. Specifically the motorized equipment at either end of the moving walkway takes up significant space, can require significant support, and needs to be accommodated architecturally in the floor support system. This "machine pit" at each end of the walkway has standard dimensions typically provided by each manufacturer in product literature.

For retrofitting moving walkways into existing structures, most moving walkway equipment can be placed above the floor line throughout most of the length. However, the machine pits at each end of the walkway must be placed below the floor level, and the accommodation of this fairly large space may be the most difficult aspect of the installation within an existing structure.

2.1.2 Effect of Walking Speeds

Moving walkways in airports are known to reduce passengers' walking distance, but little is known about their effects on airport pedestrian flows. The effect of moving walkways on pedestrian walking speeds is examined by Young (1999). Through survey data, Young found that there is no significant difference in the mean free-flow walking speeds with observed pedestrians' characteristics within airport terminals. These characteristics include the pedestrian's apparent age, the presence of baggage, the direction of travel, and party size. The survey data also revealed that average free-flow walking speed is 264 feet (80.5 meters) per minute, approximately normally distributed with a standard deviation of 52 feet (15.9 meters). This result is very similar to Fruin's study of 265 feet (80.8 meters) per minute. Srinivasan (2009) discusses that people prefer to walk on moving walkways that move at low speeds, but find it advantageous to stand when walkways move at higher speeds. Also, he considers sensory conflicts, including visual flow information and leg/muscular information that the brain must resolve when using a moving walkway.

Young (1999) compares the moving walkway with other primary modes of airport terminal passenger transportation. The results show that the average travel speed for passengers using the moving walkway was only marginally higher than for those who chose to bypass the moving walkway. Young develops a regression model to predict the travel speed and travel time of the passengers who have chosen to walk based on an empirical study of moving walkways at San Francisco International Airport. He considered many passenger characteristics, including gender, luggage, normal walking speed, and group size. In addition, discrete choice models were developed to predict the probability with which passengers will choose to use moving walkways (including the decision to walk or stand) or simply walk without assistance. In the study, the vast majority of passengers who choose the moving walkways tended to walk instead of stand on the belt.

2.1.3 Passenger Difficulty

Moving walkways do not typically involve many passenger difficulties in their use, as compared to escalators and elevators. But even difficulties that are rare can become hazardous at the exiting point of the moving walkway. In particular, passengers who are either walking or standing on the moving walkway may not recognize that they are approaching the end of the walkway where they must transition to a normal walking pace, and falls can result. Signs and recorded announcements do help mitigate this concern, but they do not eliminate the problem.

Another aspect is the presence of wheelchairs and baggage carts within the pedestrian environment where moving walkways are installed. Although signage may instruct passengers that wheelchairs and baggage carts are prohibited from use on moving walkways, the practice is not uncommon in situations where passengers must travel relatively long distances with their luggage. Conditions have been observed where wheelchairs and baggage carts have become stranded at the exit point of moving walkways due to the heavy weight that prevents the front wheels from riding up and over the top of the combplate. This occurrence, which typically happens when the person pushing the wheelchair or cart slows their pace as they approach the exit point, is caused when the front wheels reach the combplate and then begin to spin as the moving surface passes underneath and the wheelchair or cart's forward progress comes to a halt. In this situation, the device is essentially immobile until the front wheels are physically lifted up and over the combplate, which in turn creates a hazardous condition as people approaching from behind are conveyed into this blockage. Moving walkway user safety aspects are discussed by Horonjeff and Hoch (1975).

2.1.4 Capacity

It has been observed that the best definition of capacity is the rate at which users can enter the moving walkway and not the rate at which they exit. In general, the capacity of continuous moving systems, escalators, and moving walkways is not a function of the number of steps/pallets or total standing area provided (i.e., manufacturer's capacity). Arrival characteristics and human capabilities will determine the practical or working capacity of these systems. User boarding characteristics, combined with the expected traffic patterns and demand characteristics of the particular application, are the only true determinants of capacity and actual use.

2.1.5 Summary of Best Practices for Moving Walkways

The following summarizes the best practices for moving walkways:

- A series of moving walkways should be considered for assisting walking distances up to 1,000 to 1,500 feet. APMs should be considered for distances greater than 1,500 feet.
- Typically there is no significant difference in mean free-flow travel speed when comparing areas with and without moving walkways.

- Walking on the moving walkways is more prevalent on slower moving walkways (with most users walking instead of standing); standing is more prevalent on higher speed moving walkways.
- Capacity is more dependent on boarding characteristics combined with expected traffic patterns and demand characteristics and not as dependent on the physical characteristics of the specific system.
- Design of moving walkways should provide sufficient queue space to accommodate passenger surges (typically 15 to 30 feet in depth) and, if applicable, should consider the effect of other pedestrian traffic passing through the queuing area.
- Building structural design needs to provide space at each end of the moving walkway for mechanical/electrical equipment, both in length and in distance below the floor level for the machine pit.

2.2 Escalator

2.2.1 Physical Characteristics

When including escalators in an airport, several fundamental physical characteristics should be understood and taken into consideration by the designer. These characteristics include speed performance, angle/maximum rise/maximum length, step width, and provided queue areas. Each of these affects system performance and the ability to satisfy peak demands at airports.

For escalator installations in outdoor environments, ASME A17.1 requires that the escalator be covered to protect it from precipitation.

Table 2-2 shows system characteristics for escalators researched by manufacturer.

2.2.1.1 Operating Speeds

Speed on virtually all escalators in an airport environment is consistent at approximately 100 fpm (whereas that rate can approach 130 fpm for moving walkways) due to the safety element of a horizontal plane versus a rising plane. Speed on escalators anywhere is largely regulated due to safety issues and hazards associated with each landing area. For this reason, strollers,

Table 2-2. Escalator characteristics.

Manufacturer	Product/ Model	Max Speed (fpm)	Step Width (in)	Maximum Rise (ft)
Kone	ECO3000	100	24-40	49
Otis	NCE Models	**	24-40	21.3
Schindler	9300 Advanced Edition	100	24-40	24.6-55.75
ThyssenKrupp	Velino	**	24-40	33
	Tugela	**	24-40	65.6
	Victoria	**	24-40	164
Fujitec	GS8000	100	24-40	31
Stannah	A2C/S/T	**	24-40	10-29.5
Mitsubishi	J-type	100	32-48	21.3
	Spiral 1200*	80	40	11.5-21.7

* Rotation angle ranges between 103 and 170 degrees

** Information not available

NOTE: This information represents a sampling of product data from manufacturers' websites. Additional information is available directly from the equipment manufacturers.

wheelchairs, carts, and small children are often directed to elevator conveyance devices. The speeds of most escalators are adjustable and the actual operating speed may be a matter of consideration, in consultation with the operations staff at the individual airport.

2.2.1.2 Angle/Maximum Rise/Maximum Length

Accommodating long escalators and moving walkway pathways at airports is often necessary for passengers to transition between terminal and concourse floor plates, address the various service offerings, or cover long walk distances. For example, it is common practice among U.S. terminal designs to vertically separate the ticketing and baggage levels, thereby requiring a single floor change; however in instances where underground conveyances are used at larger facilities, these floor plate changes can be as much as 5 or 6 floors in total. This height further suggests a need for a maximum rise at airports of more than 100 feet. Typical maximum rises seen among manufacturers vary from 10 feet to more than 165 feet.

The angle of inclination of any escalator is limited by ASME A17.1 (Section 6.1.3.1) to a maximum of 30 degrees.

2.2.1.3 Step Width

Escalator manufacturers rate theoretical capacity based on speed, assumed occupancy per step, and 100% utilization; however, many studies show that 100% utilization is never obtained. Specifically, manufacturers use five people per four steps on a 32-inch-wide escalator, resulting in an area occupancy of 2.7 sfpp, and two people per step on a 48-inch-wide escalator, resulting in an area occupancy of 2.1 sfpp. In contrast, observed capacity is generally one person per every other step on a 32-inch-wide escalator and one person per step on a 48-inch-wide escalator, resulting in an area occupancy of 4 sfpp. Walking pedestrians do not change the capacity, given that the "boarding rate" is the capacity determinant, not the speed at which they move. At airports which experience a higher percentage of pleasure flying or are of a tourist destination characteristic, a 48-inch-wide surface is more accommodating of extra baggage. Certainly in cases where an application within a non-secure environment is planned, and the average is more than 1.5 bags per person, the 48-inch-wide escalator should be considered.

2.2.1.4 Queue Area

That escalators and moving walkways can generate large queues, even at traffic levels below the capacity of the unit is often overlooked by designers. Queuing is often generated by peak surges of passengers in an airport environment. As a result, designers must often analyze the peak 10- to 15-minute period to account for pedestrian surges on conveyance devices. Assessments of baggage quantities should also be estimated, because this will affect space requirements per person and per party. Similar to moving walkways, typical area queues range from 13 sfpp to as much as 17 sfpp. If programmed properly, this translates into standard queue platforms of between 15 and 30 feet in depth depending on the passenger surge, while the width of the queue mirrors the conveyance device width.

The absolute minimum length of clear area at the entry and exit zones of escalators is defined in ASME A17.1 (Section 6.1.3.6.4) as twice the distance between the centerlines of the handrails, and, if multiple escalators are operating in a serial configuration, this safety zone must be provided independently for each escalator. Further, the provision of a suitable queuing area at the entrance as well as an adequate safety zone at the exit end of the escalator must provide for sufficient space for the composite flows of all pedestrians moving through the area without hindering the movement to and from the escalator.

Finally, for vertical circulation system configurations where the cascading of escalators in a serial configuration creates a mezzanine level landing where people transfer to the next escalator,

the provision of ample space to absorb the fluctuations in flows exiting and entering successive units must be thoroughly assessed to avoid hazardous conditions.

2.2.2 Passenger Difficulties

During the data collection effort, at all five airports, the data collectors witnessed some passengers who had difficulty boarding or exiting an escalator. Although such difficulties were not a regular occurrence (none of the events described below occurred more than 5 times), they are worth noting. Several issues were identified as causes for these difficulties:

1. Crowding and congestion—With passengers having to pause and wait for other passengers to board the escalator, waiting passengers could not properly prepare for the device. This was most often associated with a passenger boarding the device with baggage and not being able to see the device prior to boarding. There would often be added pressure for the passenger to move quickly as there were additional passengers behind him/her in line.
2. Families with small children—Children often have very limited experience with escalators, especially in an airport environment. Typically, the parent(s) would allow the children to go first or board simultaneously (which is the better approach from a safety point-of-view). When a child was apprehensive about the device, this family would cause a blockage at the device. If the parent(s) already boarded the escalator and the child refused to board, a more significant problem occurred—Parent(s) were now trying to go in the opposite direction of the device while the child stood at the entry to the device.
3. Strollers—Strollers were regularly taken onto an escalator, and the typical effect was that they took up a bit more space. However, parents were observed boarding the escalator with the child still in the stroller rather than looking for or taking an elevator. This is a major safety issue, especially in the downward direction. While some parents successfully balanced the stroller (positioning themselves on the downward side of the stroller), we observed a few incidents where the child fell out of the stroller, and the resulting scene was chaotic. No injuries resulted from any of these incidents.
4. Wayfinding—Passengers typically use conveyance devices only when they are directly visible or clear wayfinding exists. In instances of poor wayfinding conditions, passengers were observed to use inappropriate devices (e.g., using strollers on escalators) in lieu of traveling to a non-obvious device such as an elevator.
5. Balance/fall—A passenger fell at the bottom of an escalator which caused the next few passengers to tumble over him before someone could get the escalator turned off. For the average person, it is not obvious that turning off the escalator is a two-step process, thus even a few more seconds passed (and a few more passengers fell) before the escalator actually stopped.
6. Baggage Carts—It is a rare occurrence at American airports when passengers take a baggage cart onto an escalator, but it does occur. This type of incident can be very hazardous, with situations observed in other countries where luggage fell off of heavily-loaded carts while traveling up or down escalators. To prevent this problem in European airports, it is common to place bollards in the floor surrounding the entry landing of escalators to physically prevent baggage carts from reaching these vertical circulation units.

2.2.3 Capacity

In general, the capacity of continuous moving systems, escalators, and moving walkways is not a function of the number of steps/pallets or total standing area provided (i.e., manufacturer's capacity). Arrival characteristics and human capabilities will determine the practical or working capacity of these systems. User boarding characteristics, combined with the expected traffic patterns and demand characteristics of the particular application, are the only true determinants of capacity and actual use. Therefore the capacity of a passenger conveyance system can typically be

determined within its operating environment by measurement of the number of people served in a specified period of time.

Multiple studies of escalator capacity have been performed for mass transit environments; however, the airport environment is different because of the presence of luggage and the lack of user familiarity with the facilities. A typical up escalator's capacity has been measured in an airport environment to be approximately 60 people per minute (ppm) and a typical down escalator's capacity has been observed in the same environment to have a capacity of 50 ppm. Similar capacities for escalators in an airport environment were observed and are summarized in Chapter 4 of this Guidebook. Although the capacities of moving walkway systems can be evaluated in a similar fashion as escalators, the values are different since an elevation change is not involved.

Early pedestrian studies were completed by Fruin in mass transit environments. Since those initial studies, evaluations of mass transit environments have dominated the majority of pedestrian studies. Typically, mass transit environments experience intense pedestrian demands for sustained time periods that allow for measurement and analysis of critical facility loading. Several studies evaluating the capacities of escalator systems in mass transit environments are discussed in the following paragraphs.

Pushkarev and Zupan (1975) state that human factors play a large role in defining the maximum capacity of an escalator. They claim that a manufacturer rating of 50 ppm per foot of tread-width (167 ppm per meter) cannot be achieved in practice. They suggest a maximum flow on a wide escalator (with steps designed for two people) to be about 18 ppm per foot (or 60 ppm per meter) with free arrivals and 27 ppm per foot (90 ppm per meter) under pressure from a waiting queue. Part of their findings was based on O'Neil (1974). In his study, he found that the maximum observed flow under crush conditions in subway stations was 103 pedestrians per minute on a wide escalator. For design purposes, O'Neil (1974) recommends 90 ppm as the maximum value. O'Neil further emphasizes that the flow rate in the short-term is more realistic than any hourly extrapolation and should apply well whenever the flow is fed from a waiting queue.

Based on measurements at the Port Authority Bus Terminal, Fruin (1971) found 31 ppm per foot (103 ppm meter) of tread-width to be the maximum achievable capacity. Also, Fruin (1971) calculated the maximum queue length at that rate of flow to be about 15 persons.

Barney (2003) conducted a comprehensive review of elevator and escalator capacity and flow. The author proposed a theoretical method of escalator capacity and found that an escalator with 39-inch (1-meter) nominal step width running at a rate speed of 1.64 ft (0.5 meters) per second has a theoretical handling capacity of 150 ppm. However, the author indicates that the practical handling capacity is about half of the theoretical (75 ppm) because the hesitations at boarding often result in an escalator not delivering its potential practical handling capacity.

Davis and Dutta (2002) estimated escalator capacity by using regression based on actual observations in the London Underground. They found that the capacity of an escalator at speed rate of 142 feet per minute, where passengers stood on both sides, would be approximately 108 ppm. The result is very similar to the findings in O'Neil (1974).

Pushkarev and Zupan (1975) and Davis and Dutta (2002) both state that the approaches to escalator capacity and acceptable queue lengths are open issues. Based on the cited work, the maximum observed flow of an escalator is above 100 ppm. However, due to safety and level-of-service issues, a maximum flow on a wide escalator should likely be below 100 ppm.

Although mass transit allows for the analysis of pure pedestrian environments with high demands, mass transit passengers do not typically carry luggage. Therefore this Guidebook also takes into account how luggage affects the capacity of passenger conveyance systems.

2.2.4 Summary of Best Practices for Escalators

The following summarizes the best practices for escalators:

- Human factors play a large role in escalator capacity, because the boarding process is the primary determinant; studies show a wide range of capacity values—from 30 ppm up to 100 ppm.
- Based on common practice among airport terminal planners, design capacities are typically estimated at 50 ppm for down escalators and 60 ppm for up escalators if location-specific data is not available.
- Additional step width should be considered in cases where a non-secure application is sought and there are more than 1.5 bags per person, on average.
- Although infrequent, passenger difficulties were observed at escalators including challenges with overcrowding, families with small children, strollers, balancing/falling incidents, and wayfinding signage.
- Safe design provisions must include ample space to allow entering and exiting, especially in the space between serially configured escalators.

2.3 Elevators

2.3.1 Physical Characteristics

Typically, elevators are used less frequently than other modes of passenger conveyance at airports. In most of the cases where located in the secure areas of the terminal and the airside concourses, elevators are used by those passengers requiring additional assistance, typically when the passenger is being transported by wheelchair. Many of the elevators in these areas are smaller and provided specifically for this use.

When elevators are located in the non-secure areas of the terminal and in various landside facilities, these installations often have larger elevators that are strategically placed so that they are almost a primary mode of vertical transport. These larger elevators are often required in areas where there are high levels of baggage cart use combined with the need for level changes in the passenger's travel path through the terminal and landside. For example, a significant number of MCO passengers use the elevators after they have collected their bags in baggage claim to move to curbfronts and rental car facilities on other levels of the terminal.

With respect to elevators, some fundamental physical characteristics should be understood and planned for by the designer. These characteristics include cab size, operational speeds, hauling system performance, door size, dwell requirements, number of floors served, and elevator boarding areas. Each of these affects system performance and the ability to satisfy peak demands at airports. Table 2-3 shows system characteristics for elevators researched by manufacturer.

One additional aspect of each elevator's physical characteristics that can be important to consider, even in the planning phases of work, is the provision of space for the elevator machine room. For hydraulic elevators, the machine room is typically located at the lowest level served and in a room adjacent to the elevator shaft—but it is possible to change this location in some circumstances.

For traction elevators, the hauling equipment is frequently located directly above the elevator shaft in a "penthouse" location. However, when necessary a configuration with the machine room "below" can also be provided where the equipment is located at the lowest level adjacent to and adjoining the shaft.

New elevator designs are now available which do not require an additional space for a "machine room" outside of the elevator shaft. The Machine-Room-Less (MRL) elevators are

Table 2-3. Elevator characteristics.

Manufacturer	Product/ Model	Type*	Capacity (lbs)	Max speed (fpm)	Max number of stops	Max rise (ft)
Mitsubishi	Diamond Trac	T	2,000-3,500	200-350	10	98.5
Abell Elevator International	Passenger Traction Simplex/Duplex	T	2,000-4,000	100-350	**	**
	Holeless Hydraulic	T	1,500-4,000	**	**	**
	Passenger Oil Hydraulic Simplex	H	1,500-4,000	**	**	**
	Passenger Oil Hydraulic Duplex/Multiplex	H	2,000-4,000	**	**	12
Fujitec	Talon	T	2,000-4,000	200-350	24	190
Minnesota Elevator, Inc.	Geared Traction	T	2,100-20,000	100-500	**	No Limit
	Borehole	H	2,100-20,000	200	**	75
	Holeless (Twin Jack)	H	2,100-20,000	200	**	20-40
	Roped Hydro Twin Jack	H	2,100-20,000	175-200	**	100
Schumacher	Hydraulic Passenger	H	2,000-3,500	75-200	**	**
	Traction Passenger - Gearless	T	2,000-3,500	500-1,200	**	**
Stannah	Piccolo	T/H	950-1,350	**	**	**
	Maxilift	T/H	950-2,200	**	**	**
ThyssenKrupp	SPF Traction	T	2,100-4,000	200-500	**	**
	AC Gearless	T	2,500-4,000	500-1,200	**	**
	AMEE C Series	H	2,000-2,500	100-150	**	**
	AMEE Series	H	2,100-3,500	80-150	**	**
	Conventional Series	H	2,100-3,500	80-200	**	79
Schindler	330A Hydraulic General Purpose	H	2,100-4,000	100-150	**	36-65
	400A Traction General Purpose	T	2,100-3,500	200-350	20	200
	500A Traction General Purpose	T	2,500-5,000	350-700	**	**
Otis	Holeless Hydraulic	H	2,000-3,000	100-125	3	20
	Telescopic Holeless Hydraulic	H	2,000-3,500	100-125	5	44
	Roped Holeless Hydraulic	H	2,000-3,500	100-150	7	60
	Holed Hydraulic	H	2,000-3,000	100-150	7	60
	Gen2 Machine-Roomless	T	2,100-4,000	200-400	30	196-300
Kone	EcoSpace	T	2,000-5,000	150	10	83
	MonoSpace	T	2,000-4,500	200-500	27	230
	EcoSystem MR	T	2,000-5,000	200-700	63	590
	Alta	T	2,000-8,000	700-1,600	126	1,600

* Type, T: Traction, H: Hydraulic

** information not available

NOTE: This information represents a sampling of product data from manufacturers' websites. Additional information is available directly from the equipment manufacturers.

a newer technology now available from several manufacturers. MRL elevators use permanent magnet motors to locate machinery overhead instead of in a separate machine room. Within the past few years, U.S. acceptance of MRL elevators has grown and several elevator manufacturers offer MRL elevators.

2.3.1.1 Cab Size

Cab size in an airport environment should be guided by several factors including the required system capacity measured in passengers per peak 15 minutes, specific use, area occupancies, and

level of service to be achieved during the 15-minute peak period. Specific uses include janitorial and supplies services, concessions goods, airport employee, airline personnel, public, and traveling passenger conveyance. With respect to passenger conveyance, cab size should be guided by the typical area required by each standee with or without baggage, baggage carts, or wheelchairs. Typical area occupancies may range between 1.5 sf/person to 3.5 sf/person for an uncrowded elevator, not including baggage. With baggage, typical area occupancies may increase to 10 sf/person on average. The cab size of the elevators researched above range between 40 and 55 square feet, which results in an average of 4 to 5 persons per cab.

However, in some circumstances, elevators need to be placed in locations where a large number of baggage carts are being used, and, in such locations, large special-order elevators may be required. Elevators of this size are common for medical facilities where patient gurneys must be transported, and, even when installed in airports, these large cab sizes are generally called "hospital" elevators when describing the type of equipment to be used.

2.3.1.2 Operational Speeds

The maximum speeds of the systems range from 75 to 350 feet per minute (fpm) in airport applications, although higher speeds are possible. Systems at these speeds are meant for buildings with few levels served and where speed is not of primary concern. Systems with higher speeds are intended for use in high-rise buildings and are not anticipated to be needed in an airport terminal environment. The maximum number of stops for an elevator system is closely tied to the maximum speed, since the more levels served by an elevator, the higher the speed that is required to provide suitable service times and the associated capacity.

Hydraulic elevators typically operate at speeds in the range of 75 to 150 fpm.

2.3.1.3 Maximum Height

Maximum rise refers to the maximum height an elevator system can serve. The maximum rises of systems shown above range from 12 to 1,600 feet. The maximum rise is related to the propulsion or hauling system of the elevator. Elevator hauling mechanisms can typically be divided into three categories: traction, hydraulic, and climbing. Each hauling mechanism provides different options regarding space needed for propulsion equipment, maintenance, maximum rise, and speed.

In general, hydraulic elevators are most common in buildings of two to four levels, although up to six levels may be served. Buildings with more than four levels are typically served by the other types of haul systems.

2.3.1.4 Hauling System Performance

In the airport environment, level-of-service requirements should drive the required system performance of the elevators. Hauling system performance directly translates into service times and thus level of service. Of the two most common types of elevators, traction elevators are much faster than hydraulic elevators.

2.3.1.5 Door Size and Placement

Typical passenger elevator door sizes range from 3 to 5 feet. Door size should be guided by required loading and unloading rates. In the airport environment, the higher end of the range would be more suitable in order to provide for maneuverability for passengers with baggage and wheelchairs. In a study for Ronald Reagan Washington National Airport (DCA New Terminal Project, 1992), the elevator unloading rates for elevators with 5-ft-wide doors for people without bags were 1.7 pps and 1.4 pps for persons with bags.

Larger passenger cab sizes and door widths may be necessary and are available through special order from elevator manufacturers. In particular, large cab "hospital" elevators often use a door type where larger openings can be provided when each bi-parting door panel is actually two panels that "cascade" one behind the other allowing openings of more than 5 feet—an important feature when the elevator will carry a large quantity of passengers with baggage carts.

Another feature of elevator design that allows a great deal of flexibility in the building layout is the option to place doors on both sides of the passenger cab. In particular, there are substantial benefits in some installations to providing this feature when only a few levels are to be served and where there are many baggage carts in use. This configuration with doors on both sides allows a "push on/push off" flow-through movement, eliminating the problem of requiring passengers to back their carts out of the elevator when they need to exit.

2.3.1.6 Dwell Requirements

The quality of elevator service is normally based on waiting time. A service time of 30 seconds and an average wait time of 1 minute are typical in an airport environment. The service time corresponds to the time it takes to board the elevator and includes door open time, boarding/deboarding time, time to push the elevator button, and door close time. Average wait time is the time a passenger waits for the elevator to arrive, prior to the start of the elevator service time.

2.3.1.7 Number of Floors Served

The number of floors served directly affects the elevator round-trip time which is the time taken to service all floors. In an airport terminal environment, the number of floors served will be limited by building height restrictions. Hauling performance should be provided so as to meet required service times.

2.3.1.8 Elevator Boarding Areas

Boarding areas should provide adequate space for passenger queuing. Passenger queuing area occupancy averages 20 sfpp around elevator boarding areas in an airport environment. Additional queuing capacity is provided with additional elevators. Furthermore, when baggage carts are to be accommodated, sufficient space for cart maneuverability must be also provided.

As seen in Figure 2-1, this example from MCO shows that three large elevators are provided in the baggage claim area to transport passengers to ground transportation and parking. Queues often form at these elevators because groups of people depart baggage claim at similar times.

Figure 2-1. Queue at elevators at baggage claim, MCO.

Figure 2-2. Passenger queue for elevator in concourse, ATL.

Figure 2-2 shows passenger queues in ATL waiting to travel to the APM level. As stated previously, elevator users are primarily stroller or wheelchair patrons.

2.3.2 Wheelchair Lifts

A specialized subset of elevator systems includes wheelchair lifts. These systems are designed to move a wheelchair a shorter distance than typical elevators. As shown in Table 2-4, the maximum rise of these systems ranges from 4 to 23 feet. These systems typically accommodate only one person in a wheelchair at a time. Maximum load capacities range from just under 500 to 1,000 pounds.

Table 2-4. Wheelchair lift characteristics.

Manufacturer	Product/Model	Capacity (lbs)	Platform Area (ft^2)	Max Speed (fpm)	Max Number of Stops	Max Rise (ft)
Savaria Concord	Profit SCL	750-1,000	n/a	30	5	23
ThyssenKrupp Access	Porch-Lift Standard	750	12-17.5	12-21	3	14
	Porch-Lift Toe Guard	750	15	12-21	2	4
	Porch-Lift Enclosure	750	15	12-21	3	14
	Porch-Lift Portable	750	12	12	2	6
Inclinator	SpectraLift	750	12-15	20	n/a	4
	Inclinator VL	750	12-15	10	n/a	12
Garaventa Lift	Artira (Inclined)	550	7-10.5	10-20	7	n/a
	Xpress II (Inclined)	495	7-10.5	13-16	1	n/a
	Enclosure (Lift)	750	n/a	10-17	2-3	n/a
	Shaftway (Lift)	750	n/a	10-17	2-3	n/a
	OPAL (Lift)	750	n/a	10-17	2	n/a
	STAAGE (Lift)	750	n/a	10	2	n/a

n/a: Information not available

NOTE: This information represents a sampling of product data from manufacturers' websites.

Wheelchair lifts are rarely seen in an airport environment, except in smaller terminal facilities or possibly at the apron boarding level. Typically, wheelchair access to various floors in terminal facilities is satisfied by elevator conveyance devices—wheelchair lifts are isolated devices oriented to one particular function, and the resulting speed and capacities are significantly less than that of an elevator. Wheelchair lifts are often implemented to bring existing facilities into compliance with Americans with Disabilities (ADA) requirements if no other alternatives are feasible. The information in Table 2-4 outlines the physical and performance characteristics of wheelchair lifts available in the market today.

Device capacity ranges from approximately 500 to 1,000 pounds. The maximum speed varies from 10 to 30 fpm, while the maximum rise is less than 25 feet.

2.3.3 Passenger Difficulties

Two common difficulties for elevator users were observed during data collection activities associated with the preparation of this Guidebook—elevator door conflicts and wayfinding within the airport to gain access to elevators.

Regarding elevator door conflicts, observations have shown that baggage carts and wheelchairs are sometimes forced between the elevator doors as they are closing in order to enter before the doors are fully closed or even to intentionally contact the door edge in order to cause them to cycle open again. This can cause a considerable amount of damage to the elevator door systems and risk injury to passengers. In one observed instance, an attendant pushed a wheelchair into an elevator with such force that the chair knocked over a piece of luggage and a passenger inside the elevator. In general, some delays will occur when a passenger tries to force doors that are already closing to reopen and allow another passenger to board. Although this allowed the additional passenger onto the elevator, it resulted in a longer dwell time and thereby reduced capacity.

Many airport vertical circulation systems are now designed with the escalator as the primary mode, particularly as roller bags allow greater mobility of passengers with luggage in their possession. When passengers prefer an elevator, it is important that either the line-of-sight and/or signage allow clear wayfinding to reach the alternative conveyance. Some people will not take extra time to find the elevator option, as witnessed with parents taking a child in a stroller down an escalator rather than the elevator because the elevator was some distance away and not visible from the escalator. In another instance, the signage for the elevator did not indicate the same destination as the escalator, causing confusion among passengers. Inside the elevator, the labeling of the floors/stops need to match the signage and/or clearly identify the passenger destination rather than just the floor numbers.

2.3.4 Capacity

Capacity of elevator systems can be measured in different ways—either in sfpp (based on the elevator cab area and other space-related criteria) or by the amount of waiting time a typical passenger experiences (which is a function of operational characteristics of the specific equipment).

Load capacities of the elevator systems range from 950 to 20,000 pounds. Elevator cab size and door size can play a key role in determining system capacities and level of service for the chosen system but vary greatly across manufacturers. Elevators with larger doors can accommodate a higher passenger boarding/deboarding rate, thereby reducing the elevator service time at each stop. Furthermore, larger cabs can accommodate more people and reduce the need for multiple stops to accommodate larger travel parties.

2.3.5 Summary of Best Practices for Elevators

The following summarizes the best practices for elevators:

- Elevators in an airport environment are primarily used by passengers with mobility issues.
- Line-of-sight and/or signage to the elevator should be obvious for those that need it and to reduce wayfinding confusion.
- Capacity is a function of several characteristics, including speed, number of stops, cab floor area, dwell times, and passenger demand patterns between levels of the building.
- When intended for extensive use of passengers with baggage carts, cab configurations often have large door widths and flow-through door configurations (i.e., doors on each side of the cab). These large units are typically ordered as special-order hospital-size elevators with large cab sizes.
- Wheelchair lifts are recommended to bring existing facilities into compliance with ADA requirements if no other alternatives are possible.

2.4 General Maintenance Considerations

As part of the data collection effort, the research team also discussed maintenance costs of the various conveyance systems with airport staff. Many airports have third-party providers that maintain and support the systems. Such arrangements may be made through contracts managed directly by the airport or by the tenant airline(s). Some contract providers or airline consortiums were uncomfortable providing dollar amounts because they consider costs to be sensitive or proprietary information. Seattle-Tacoma International Airport (SEA) provided maintenance costs—their staff had recently evaluated the costs of maintaining the older installed units as compared to replacement costs.

The maintenance cost information obtained from the airports is summarized in Table 2-5. In addition, MCO provided an average annual maintenance cost of $399 per wheelchair lift. SEA evaluated maintenance costs of freight elevators separate from passenger elevators, with freight elevator maintenance ranging from $7,248 to $14,160.

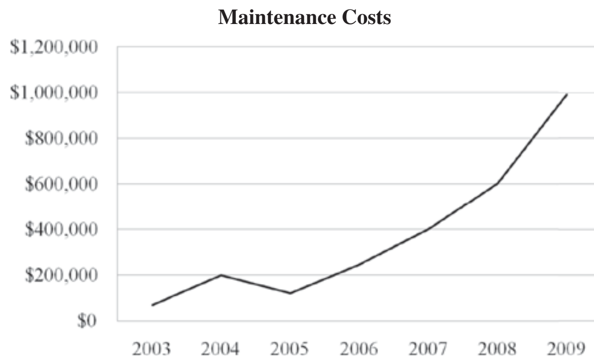
Various factors affect the maintenance costs of elevators, escalators, and moving walkway equipment. For example, when equipment is installed where it is exposed to outdoor environments, the design of the machinery must be specified for this use and the maintenance costs will be greater.

Because of escalating corrective repair costs and the unreliability of their aging equipment, SEA undertook a replacement modernization capital program to update this infrastructure over a 4- to 5-year timeframe at a cost of $80 million. This investment was based on the costs of the corrective repairs, as seen in Figure 2-3. Most of this equipment is approximately 30 years old. Note the five-fold rise in maintenance costs in the last 5 years.

Table 2-5. Passenger conveyance annual maintenance cost, per unit.

<table>
<tr><th rowspan="2">Mode</th><th colspan="4">Airport</th></tr>
<tr><th>DFW</th><th>DEN</th><th>MCO</th><th>SEA</th></tr>
<tr><td>Elevator</td><td>$3,319</td><td rowspan="2">$14,235</td><td rowspan="3">$12,194</td><td>$3,564 - $15,108</td></tr>
<tr><td>Escalator</td><td>$14,441</td><td>$12,276-$16,044</td></tr>
<tr><td>Moving Walkway</td><td>*</td><td>*</td><td>$12,420</td></tr>
</table>

* not available



Source: Seattle-Tacoma International Airport

Figure 2-3. SEA escalator annual maintenance costs.

Comparisons of different types of passenger conveyance systems provide useful maintenance cost data for consideration in the planning of building vertical circulation systems. Information provided by DFW included information that the operations and maintenance costs of operating an escalator are significantly higher than those of a two-stop hydraulic elevator, because an escalator consumes electricity the entire time it is in service. However, a hydraulic elevator uses nominal power unless running in the up direction. DFW estimated that, even at maximum usage, the elevator is operational only about 33% of the time. Escalators are also prone to more maintenance hours and more expensive damage repair, such as cuts in handrails and damaged steps. Operating escalators also carries a greater liability with significantly more recorded incidents than the elevator equivalent.

The elevator costs shown in Table 2-5 cover a large range of elevator designs and drive systems. The wide range of annual maintenance costs—with the highest cost more than 4 times the lowest cost—are indicative of the differences between hydraulic elevators at the lower end of the cost range and traction drive elevators at the higher end of the cost range. Also significantly affecting the annual maintenance costs is the number of levels served by the different elevators.

CHAPTER 3

Design Considerations

Various best practices and design considerations should be evaluated when designing passenger conveyance systems. In particular, passenger characteristics and passenger walking distances will affect the types of passenger conveyance devices chosen.

3.1 Physical Characteristics—Passenger Walking Distance

Many sources describe the process and guidelines for airport terminal planning (e.g., Ashford et al. 1996, Dempsey 2000, Omer and Khan 1988). In the *Apron and Terminal Building Planning Manual,* the Ralph M. Parsons Company (1975) also provides guidance for planning airport apron-terminal complexes. They briefly discuss circulation; however, there is little mention concerning the effects of walking distances on passengers and their walking distance preferences. The Federal Aviation Administration (1994) mentions the possibility of installing moving walkways, escalators, and so forth to make excessive walking distances more tolerable.

In *Planning and Design of Airports,* Horonjeff, et al. (2010) state that walking distance should be examined and considered in the terminal design development. As with other planning and design references, very few insights into acceptable walking distances are provided. Wells (2004) and Odoni and de Neufville (1992) also mention that airports should consider minimizing walking distances for passengers when designing terminal building space requirements. Another widely used planning guideline is provided by IATA (International Air Transport Association 2004), which suggests a maximum passenger walking distance of between 820 and 985 feet (250 and 300 meters) unaided and up to 2,133 feet (650 meters) with moving walkways.

Delve (2004) mentions that size and positioning of escalators and other people mover systems at airports are very important to minimize the time and distance that passengers travel. He also suggests a strategy for exposing passengers to various revenue-generating sites such as stores and restaurants while proceeding through the terminal. As such, design projects are not always focused on improving passenger travel time efficiency. Russell (2004) reviews a project to expand the number of service stands at London's Gatwick Airport. The focus of this article is on the use of a new passenger bridge that connects the North Terminal with the Pier 6 satellite building. Although not specifically designed to reduce passenger travel times, the bridge provides passengers with a direct pedestrian link to aircraft, saving an estimated 50,000 coach journeys a year. With 200-ft (61-m) long moving walkways and 33 feet (10 meters) between each moving walkway, the bridge also provides an enjoyable walking experience for passengers.

Walking distance and walking speed are significant factors when installing automated pedestrian movement systems within airport terminals. Seneviratne (1985) proposes an

approach for determining critical pedestrian walking distance. Based on findings from a series of surveys in Calgary, Alberta, the critical pedestrian walking distance distribution was found to be dependent on the classification of the pedestrian. The results show that the best walking distance distribution for most work-based trips follows a gamma distribution and the critical distance is estimated at 796 feet (243 m). This is the same methodology first introduced by Pushkarev and Zupan (1975), where they identified a critical walking distance distribution for urban areas. They report that average walking distances in central London were more than 2,625 feet (800 meters), whereas those in midtown New York City were 1,719 feet (524 meters). Moreover, Pushkarev and Zupan (1975) state the advantages and limitations when using an escalator and a moving walkway. However, they leave the optimal length of a moving walkway as an open issue. In order to solve this problem, Bandara and Wirasinghe (1986) and Bandara (1989) develop an analytical model for optimizing pier-type terminal configurations. They consider an objective function that minimizes the sum of system operational costs and individual user costs to determine the optimal length of the moving walkway. Seneviratne and Wirasinghe (1989) performed a cost analysis with the goal of optimizing airport terminal corridor width.

When discussing walking speed, walking distance, and level of service of facilities in public, Fruin (1971) conducted a series of studies on the behavior of pedestrians within transportation terminals. Two studies in particular conducted at the Port Authority Bus Terminal and at the Pennsylvania Train Station, both in New York City, observed pedestrian walking speeds under free-flow conditions along with various observable pedestrian characteristics. Fruin found that the mean walking speed was approximately 265 feet (80.8 meters) per minute, with a standard deviation of 50 feet (15.3 meters) per minute.

Only a few specific physical characteristics of the terminal facility, such as distance between gates and location of security points, affect the specific passenger walking distances required.

3.1.1 Distance Between Gates

The physical distance between the gates will directly affect the walking distance required. If the terminal has a long distance between gates, passenger conveyance devices should be considered. Furthermore, if access to the gates requires elevation changes, design considerations regarding the appropriate type and location of vertical circulation devices will be required.

In addition, the connection ratios and gate assignments for individual airlines could affect the walking distance required. For example, if an airport is a large hub for a specific airline, that airline could use a large number of gates that extend over different terminals. In those high connection airports, particular design considerations should be given to the walking distance and resulting walking time requirements.

3.1.2 Location of Security Points

The location of the passenger conveyance devices relative to the security checkpoints should be considered in the design. Passenger conveyance devices located prior to security checkpoints will frequently carry passengers who have a higher number of bags. Furthermore passengers in the unsecure areas of the terminal are typically more conscious of travel time since they may have several tasks to complete prior to flight departure (e.g., checking bags and printing boarding passes).

In contrast, post-security passengers often have (1) less baggage and (2) a better understanding of available free time in relation to flight departure time. In those instances, passengers may select more leisurely passenger conveyance devices that actually increase their walking distance in order to use available retail or other airport services.

3.1.3 Multi-level Parking Garage Size

Finally, the walking distances required in parking garages should also be evaluated when designing the number and types of passenger conveyance devices required within the garage. Parking garages are typically more exposed to the weather and, depending on location, could experience extremely high or low temperatures. Furthermore, passengers will have their entire luggage when traveling in the parking garages. Zacharias (2001) discusses acceptable walking distances in city areas and provides suggestions for further research-based development of methods to plan effectively. Based on the results of the study, it can be inferred that the walking distance is proportional to the concentration and distribution of activities in the immediate area. This should be a consideration when designing the parking structure conveyance elements and expediting the passengers' travel to ticketing. Smith and Butcher (2008) discuss the various types of parking facilities, various conditions (e.g., protected or unprotected), and the corresponding acceptable walking distances. Specifically related to airports they note the following: "For example, an airport to be designed for LOS A would want to have a maximum path of travel of 300 feet from the parking space to the elevator within a parking facility, and a weather-protected path of no more than 500 feet from the elevator lobby to the terminal. There may then be a climate controlled path of no more than 1,000 feet from the entrance to the terminal to the gate. The overall path of travel should not exceed 2,400 feet (LOS B)."

3.2 Passenger Characteristics

Passenger characteristics affect walking distance and walking speed. Similarly, passenger characteristics affect choice of passenger conveyance. When quantifying pedestrian movement, Hui et al. (2007) found that walking speed, step size, and step frequency all followed normal distributions. Step frequency was significantly affected by gender and age. With the exception of children and older pedestrians, walking speed and step size were also significantly affected by gender and age. These results were based on data collected in Beijing, China. Helbing (1991) provided a more specific perspective by presenting a mathematical model for the movement of pedestrians.

3.2.1 Typical Age

The age of the passenger will often affect the selection of passenger conveyance. In particular, passengers in wheelchairs or other mobility assistance devices and passengers with strollers will often use an elevator as the primary means of vertical conveyance. Wheelchairs and strollers are often not allowed on moving walkways. Furthermore, the experience and comfort level with circulation elements such as moving walkways and escalators also will affect the choice of passenger conveyance.

Issues with balance and vertigo, challenges often faced by older passengers, influence some passengers to choose elevators rather than escalators. During the data collection, a few individuals specifically sought out an elevator to avoid riding on an escalator. Older passengers expressed concerns with balance in not being comfortable on an escalator. One passenger commented that riding on an escalator would cause her to become sick.

An example of the impact of age on passenger conveyance choice was observed in Orlando. With the large numbers of families visiting the theme parks in the Orlando area, the research team observed more situations at MCO with children having problems using escalators. These problems often caused a few seconds of delay for boarding at the top of the escalator. As shown in Figure 3-1, the picture on the top shows adults folding up the stroller while the child spends a few seconds getting comfortable before boarding the escalator. On the bottom, the child and adult first approached the escalator, but then walked to the stairs when the child did not want to board the escalator.

Figure 3-1. Children with escalator boarding difficulty, MCO.

3.2.2 Number of Connecting Passengers

The number of connecting passengers also can affect the vertical circulation choice. In many instances, the connecting passengers may have a limited amount of time to travel between gates, resulting in a shorter desired travel time. As such they will often elect the fastest passenger conveyance devices to minimize their time between gates.

In addition, the connecting passengers may not be as familiar with the airport as a typical originating/terminating passenger. Connecting passengers will often rely on line-of-sight and the available wayfinding signage to direct them to passenger conveyance devices.

3.2.3 Domestic Versus International Travelers

Similarly, international travelers may be unfamiliar with the airport. Furthermore, if the local language is not the passenger's primary language or if the passenger does not speak the local language, wayfinding could be particularly difficult and such passengers may require assistance. In these instances line-of-sight may be the primary means of selecting passenger conveyance modes.

3.2.4 Average Party Size

Often larger party sizes travel together for flight travel. The passenger conveyance choice for an individual passenger may vary dramatically from a family that is traveling together. For example, a single passenger may more quickly be able to navigate onto an escalator or use an uncongested stair; a larger party may often choose a different passenger conveyance device, such as an elevator, to ensure that the travel party remains intact.

3.2.5 Business or Leisure Trips

The type of trip, business or leisure, also affects the passenger conveyance choice. Depending on the frequency of travel, business travelers are often familiar with the airport and can select the passenger conveyance that minimizes their travel times, even if the conveyances are not intuitively obvious.

In contrast, leisure trips may often consist of passengers who are not frequent travelers. Such passengers may not be familiar with the airport layout and conveyance modes. Furthermore, the travel parties are often larger and have a wider variation in age. Therefore, leisure trips may rely more on the wayfinding signage and line-of-sight to select passenger conveyance devices.

CHAPTER 4

Overview of Decision-Making Framework

The following chapter summarizes the overall decision-making process for evaluating passenger conveyance in an airport. Two example decision-making trees are summarized and described within this chapter, including the input decisions needed. Following the general description of the decision-making trees, there is further discussion regarding observed behaviors at several airports nationwide. Several tables are included in the following sections that summarize the observed behaviors, but additional information including the sample size and standard deviation are included in the database.

4.1 Framework Structure and Use

Two example decision-making trees are provided that illustrate a general flow of the design process. The first decision-making tree, Figure 4-1, begins with the anticipated passenger flows and tracks their trip throughout the airport to calculate the flow rates for different decision points throughout the airport.

The second decision-making tree, Figure 4-2, summarizes the evaluation aspects for vertical conveyance systems and horizontal conveyance systems. This figure tracks the evaluation criteria, such as area and rise, and shows considerations when recommending different types of passenger conveyance systems.

4.2 Inputs and Choices Needed for Decision-Making Trees

4.2.1 Expected Flow Rate

IATA's *Airport Development Reference Manual* (2004) indicates that passenger traffic peaking at airports has been the subject of increasing concern by airline and airport operators around the world and it recommends using schedule coordination to manage capacity demand. The airport development reference manual gives comprehensive definitions of capacity in airports but not specific capacity numbers or estimates for conveyance systems in particular. Researchers have attempted to gauge the practical capacity of conveyance systems, with differing results across the studies. One clear theme does emerge: manufacturer theoretical capacities can rarely be achieved in practice.

Although in some airport applications, capacity and demand can be measured in hourly flows, in evaluation of the passenger conveyance devices surge flows have a large effect on the device performance. Therefore, the passenger flows and corresponding capacity evaluations

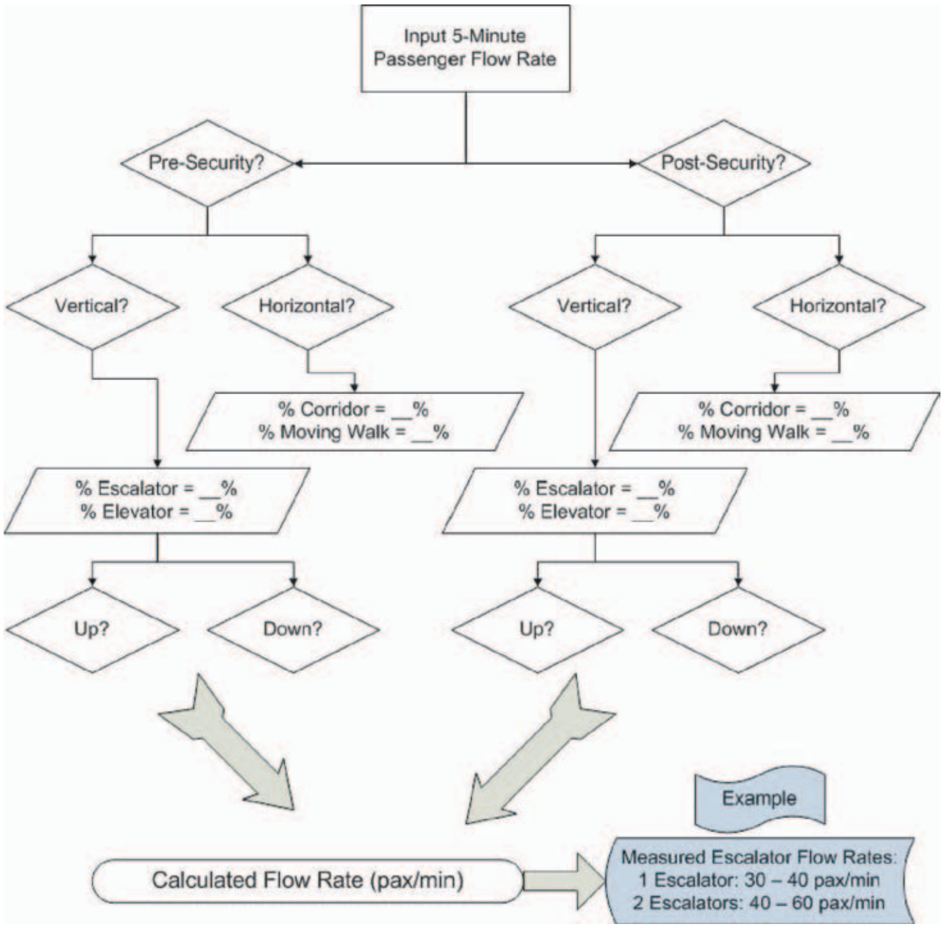


Figure 4-1. Framework of the decision-making tree 1.

are typically measured in smaller intervals, such as 5-minute peak flow rates. Large passenger surges of short durations often occur at airports as planes unload or as APMs arrive at stations. Typically a 5-minute passenger flow takes into account some of the short duration peaks without overconcentrating the flows. More information on the 5-minute flow rate calculation is provided in other sections of the Guidebook.

4.2.1.1 Location of Conveyance

The decision-making tree identifies a decision point based on the location of the passenger conveyance devices because, as discussed in the design considerations section, the location of security checkpoints relative to the devices will affect the design. Joy (2001) presents a historic synopsis of secure versus non-secure travel path issues at George Bush Intercontinental Airport/Houston, then examines non-secure inter-terminal passenger conveyance alternatives for the airport as a case study. Kyle (1998) conducted a study and presents a discrete-event simulation model to examine how existing and future operations would affect the mobile lounge fleets. The following sections summarize different locations of conveyance devices and how they affect passenger flows.

Pre-Check-In or Post-Baggage Claim. At locations where passengers have not checked-in for their flight, they typically have significantly more baggage. This baggage can contribute to a

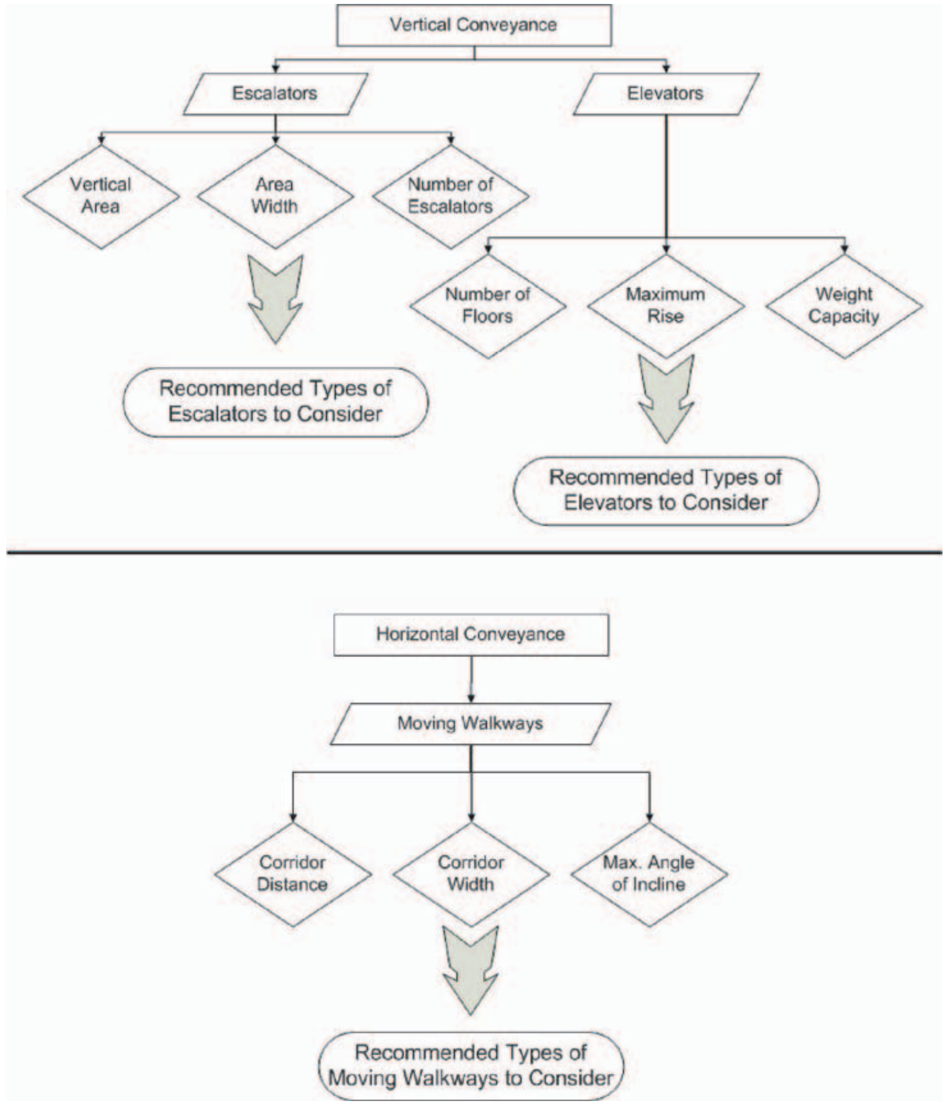


Figure 4-2. Framework of the decision-making tree 2.

significant space requirement of passenger conveyance devices. Furthermore, the use of baggage assistance devices (i.e., baggage carts) can affect the passenger conveyance choices available.

Post Check-In, Pre-Security. After checking in at the ticket counter or bag drop location, passengers will only have their carry-on luggage. This will result in a lower passenger space requirement because larger bags will be separated from the passengers. However, pre-security passengers may still have some timing concerns (e.g., uncertainty in how long security may take, distance to gate, and flight status) and look for savings in walking time, thereby selecting faster modes of passenger conveyance to minimize transit time and delays.

Post-Security. As described in the design considerations, passengers post-security have lower baggage space requirements and often have a higher comfort level. In these instances, passengers may select more leisurely passenger conveyance devices that increase their walking distance in order to use available retail or other airport services because they have a better understanding of available free time before their flight departure time.

Table 4-1. Passenger vertical conveyance mode choice (in percentage of persons) by airport.

Airport	Elevator Percentage	Stair Percentage	Escalator Percentages		
			Total Percent	*Percent Walk on Escalator*	*Percent Stand on Escalator*
ATL	2.32%	0.19%	97.48%	*6.75%*	*93.25%*
CLT	2.97%	9.17%	87.86%	*8.51%*	*91.49%*
DEN	2.82%	4.68%	92.51%	*12.64%*	*87.36%*
DFW	3.61%	2.98%	93.42%	*10.75%*	*89.25%*
MCO	19.03%	8.21%	72.77%	*5.91%*	*94.09%*

4.2.1.2 Vertical or Horizontal Conveyance Needed

The next decision within the decision-making tree is the area to be traversed: horizontal or vertical. With horizontal conveyance, the airport planners can choose to provide a moving walkway. For vertical conveyance, the options include elevators, escalators, and stairs.

4.2.1.3 Percent of Passengers Expected to Use the Conveyance

The decision-making tree requires estimates with respect to usage of each of the various conveyance devices. As a point of reference Table 4-1 shows the passenger vertical conveyance mode choice by airport, based on the data collection effort. In all cases, the escalator is the preferred mode for a vertical transition, with passengers predominantly standing on the device. However, a much higher percentage of passengers use elevators at MCO—This is directly related to the placement and the available number of elevators. Passengers are clearly presented an elevator option at MCO in two key locations: (1) entrances to the terminal from rental car return and parking lots and (2) near the baggage claim areas.

Table 4-2 shows the passenger vertical conveyance mode choice by airport and by direction of travel.

In most cases, there is a further distance to the elevators; therefore, most passengers do not perceive the elevators to be as convenient access, as illustrated in Figure 4-3. However, the

Table 4-2. Passenger vertical conveyance mode choice (in percentage of persons) by airport and direction.

Airport	Direction	Elevator Percentage	Stair Percentage	Escalator Percentages		
				Total Percentage	*Percent Walk on Escalator*	*Percent Stand on Escalator*
ATL	Down	2.66%	0.09%	97.25%	*7.18%*	*92.82%*
ATL	Up	2.03%	0.28%	97.68%	*6.38%*	*93.62%*
CLT	Down	3.42%	8.46%	88.12%	*7.97%*	*92.03%*
CLT	Up	1.32%	11.75%	86.93%	*10.54%*	*89.46%*
DEN	Down	1.62%	7.48%	90.89%	*12.85%*	*87.15%*
DEN	Up	4.81%	N/A	95.19%	*12.31%*	*87.69%*
DFW	Down	4.90%	1.77%	93.33%	*13.05%*	*86.95%*
DFW	Up	2.26%	4.23%	93.51%	*8.36%*	*91.64%*
MCO	Down	16.88%	9.72%	73.40%	*5.88%*	*94.12%*
MCO	Up	30.70%	N/A	69.30%	*6.11%*	*93.89%*

N/A – information not available

Figure 4-3. Escalators and elevator in Skylink station, DFW airport.

research team observed that most passengers taking elevators were those that required them for mobility (e.g., wheelchair or stroller).

As mentioned in the design considerations section, the amount of baggage will affect the passenger conveyance choices.

Table 4-3 shows the average number of rolling carry-on luggage, or roller bags, by passenger, by airport and the chosen vertical conveyance mode. Although passengers regularly have a roller bag when using escalators for vertical transition, approximately 90% would choose to stand on the escalator. This result was consistent across all airports. The values in Table 4.3 represent the average number of roller bags per person by mode. Unlike the previous tables, this number does not directly correspond to the percent of passengers using roller bags, because some passengers may carry multiple roller bags.

The anticipated flow rate will also affect the passenger conveyance choice. As one or more of the passenger conveyance devices approach or exceed capacity, certain passengers may choose to use a different mode of conveyance. For example, with the surge of people approaching the escalators to baggage claim, many people would simply take the stairs rather than queue for the escalator. Figure 4-4 shows the bottom of the escalators and stairs where the passengers are exiting to baggage claim at MCO.

Table 4-4 shows the passenger horizontal conveyance mode choice by airport.

Table 4-3. Number of roller bags by airport and by passenger vertical conveyance mode.

Airport	Elevator	Stairs	Stand on Escalator	Walk on Escalator
ATL	0.26	0.21	0.40	0.10
CLT	0.36	0.09	0.41	0.08
DEN	0.46	0.03	0.30	0.07
DFW	0.40	0.03	0.38	0.07
MCO	0.69	0.05	0.39	0.08

Figure 4-4. Escalator and stairs to baggage claim, MCO airport.

More than half of all passengers will use moving walkways when given the choice. For those using the devices, most passengers choose to walk on them to quicken their trip.

Table 4-5 shows the moving walkway board rates collected.

4.2.1.4 Is Vertical Conveyance Serving Passengers Traveling Up or Down?

The number of required devices will vary based on the passenger flows expected at the individual locations. In the Skylink stations at DFW, there are three escalators at each end of the station, with two in the "down" direction and one in the "up" direction. Only one is needed in the "up" direction because passengers arrive at the station at varying times. Two escalators are needed in the "down" direction to handle the surge of passengers all exiting a train at the same time. Having three escalators available also minimizes disruptions when an escalator is out of service for maintenance, as shown in Figure 4-5.

4.3 Special Considerations for Conveyance Modes

There are a number of special considerations when determining the proper conveyance mode. These include the flow rate of passengers and the area characteristics that need to be served. Flow rate is important because it helps to plan the number of passengers the conveyance mode

Table 4-4. Passenger horizontal conveyance mode choice (in percentage of persons) by airport.

Airport	Corridor Percentage	Moving Walkway		
		Total Percentage	*Percent Walk on Moving Walkway*	*Percent Stand on Moving Walkway*
ATL	35.62%	64.38%	*91.03%*	*8.97%*
CLT	47.27%	52.73%	*85.35%*	*14.65%*
DEN	30.36%	69.64%	*85.78%*	*14.22%*
DFW	45.23%	54.77%	*91.32%*	*8.68%*
MCO	28.71%	71.29%	*70.74%*	*29.26%*

Table 4-5. Moving walkway board rates, by airport.

Airport	Moving Walkway Width (in)	Board Rate (ppm)
ATL	40	57
CLT	40	52
DEN	60	56
DFW	40	33
MCO	48	67

will need to be able to accommodate. Area is important so that the user will accommodate the infrastructure conditions. For example, with a low passenger flow rate and no vertical needs, a moving walkway may be better; when there is a large passenger flow with vertical changes and significant horizontal distances, an elevator, escalator, or moving walkway combination may be the most appropriate choice.

To assist the user, this section analyzes and summarizes the data pertaining to escalators, elevators, and stairs to determine the average escalator board rates as a function of airport, direction of travel, escalator tread-width, and number of escalators; the average elevator board times as a function of airport and boarding type (boarding or deboarding); elevator passenger characteristics; passenger vertical conveyance mode as a function of airport and direction of travel; and average number of roller bags as a function of airports and passenger vertical conveyance mode.

4.3.1 5-Minute Flow Rate Calculation

Capacity determinations involving periods of time (e.g., people per minute, passengers per hour) are typically evaluated in rounded time periods such as per second, per minute, per hour, or per day. However, passenger conveyance systems in an airport environment experience different loading patterns than other environments where these systems are in use.

For example, an escalator system in an airport terminal environment delivering passengers from their arriving flight to a baggage claim level below may handle a heavy loading period for

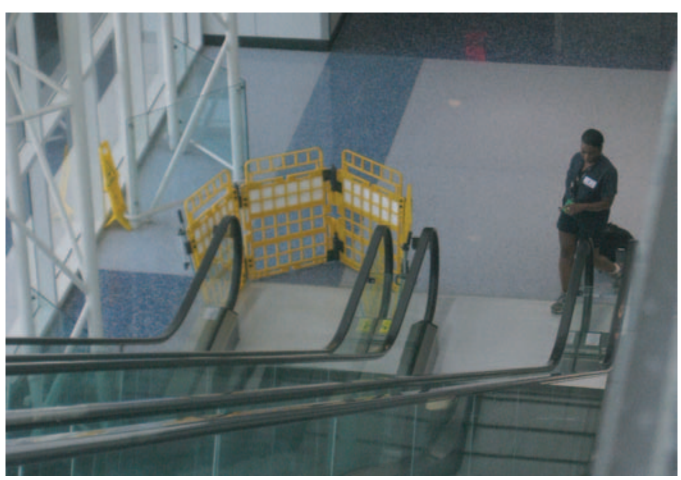


Figure 4-5. One of three escalators out of service, DFW airport.

a 5- to 15-minute period. In this instance, establishing a capacity level on a per-hour basis or longer is not relevant to the situation because the non-peak period for the remainder of the hour counteracts the peak passenger flow in determining capacity. A per-minute capacity determination may not be appropriate either because the surged 1-minute flows overrepresent the passenger demands on the system. As a result, a non-uniform time period for capacity determination (e.g., passengers per peak 5 minutes, passengers per peak 15 minutes) could be useful and more appropriate to the airport environment.

The 5-minute flows can be observed in the field by doing a series of 5-minute observations. Otherwise the hourly flows can be divided by the desired interval and a peaking factor can be applied to represent the appropriate peaking.

4.3.2 Considerations for Escalators

As a final comprehensive view of escalator board rates, Table 4-6 shows the board rates per escalator by airport, number of escalators in the bank, direction of travel, and tread-width. The table provides some real-world applications of how variable the board rate can be for one, two, or three escalators, considering the other factors.

Table 4-7 shows the average escalator board rates by airport.

Table 4-8 shows the average escalator board rates by airport and by tread-width. It shows that a higher board rate is observed for wider escalators in ATL, but lower board rates for wider escalators in DEN. Again, this is largely due to airport configuration. In particular, the wider escalator may be located in an area where the demand is higher.

Table 4-6. Average escalator board rates (in persons per minute per escalator) by airport, number of escalators, direction, and width (in inches).

Airport	Number of Escalators	Direction	Board Rate	Width
ATL	1	Down	35	36
ATL	1	Down	36	48
ATL	1	Up	43	40
ATL	2	Down	25	48
ATL	2	Up	32	48
ATL	3	Down	19	36
ATL	3	Down	19	48
ATL	3	Up	32	48
CLT	1	Down	32	40
CLT	1	Up	35	40
DEN	1	Down	49	48
DEN	1	Up	56	48
DEN	2	Down	18	40
DEN	2	Down	28	48
DEN	2	Up	38	40
DEN	2	Up	33	48
DFW	1	Up	36	48
DFW	2	Down	26	48
MCO	1	Down	38	38
MCO	1	Up	33	38
MCO	2	Down	32	38

Table 4-7. Average escalator board rates per escalator (in persons per minute) by airport.

Airport	Board Rate
ATL	31
CLT	34
DEN	39
DFW	32
MCO	33

Table 4-8. Average escalator board rates (in persons per minute) per escalator by airport and tread-width (in inches).

Airport	Board Rate (ppm)	Width (in)
ATL	25	36
ATL	43	40
ATL	30	48
CLT	34	40
DEN	35	40
DEN	45	48
DFW	32	48
MCO	33	38

4.3.2.1 Up Versus Down Passenger Travel

Table 4-9 shows the average escalator board rates by airport and by up (U) and down (D) directions across all escalators at that airport observed. Escalator board rates for passengers going up are higher than passengers going down. In general, it is believed that passengers may slow their board rate when going down as the entire device is not visible when boarding.

4.3.2.2 Number of Escalators

Table 4-10 shows the average escalator board rates by airport and by number of escalators. As the number of escalators is increased additional capacity is added, but the increase is not linear. For example, the addition of a second escalator adds capacity but does not double capacity. The board rate per individual escalator is dependent on the use and placement of the escalator bank. When bulk queues are combined in front of multiple escalators the effect of people moving through the larger queuing space and the additional decision time associated with choosing between escalators regulates and meters the flows onto the escalators. This results in lower board rates for multiple, adjacent escalators.

4.3.2.3 Effect of People Movers—Surge Effects

The research team observed several queues of passengers waiting to access escalators (see Figure 4-6 through 4-9). When passengers exit from a full APM train, there is typically a short walk distance from the train to the escalators in most of the concourses. Due to the volume of

Table 4-9. Average escalator board rates (in persons per minute) per escalator by airport and direction.

Airport	Board Rate	
	Up	Down
ATL	34	28
CLT	35	32
DEN	43	28
DFW	36	26
MCO	33	33

Table 4-10. Average escalator board rates (in persons per minute per escalator) by airport and number of escalators.

Airport	Number of Escalators	Board Rate
ATL	1	39
ATL	2	28
ATL	3	28
CLT	1	34
DEN	1	55
DEN	2	34
DFW	1	36
DFW	2	26
MCO	1	38
MCO	2	32

Figure 4-6. Passenger queue for escalator to APM, ATL.

Figure 4-7. Passenger queue for escalator from APM station, ATL.

Figure 4-8. Passenger queue for escalator from APM, ATL.

Figure 4-9. Queue developing at top of escalators, MCO.

passengers exiting the train, a queue develops at the escalator(s), which were observed to be 40 feet long in some instances. When the next train arrived, the last passenger from the previous train was just boarding the escalator. It can be assumed that during peak periods of the year, there are times when passengers are still in queue for the escalator when the next train arrives at the station.

4.3.3 Considerations for Elevators

Table 4-11 shows the average elevator board times and passenger characteristics by airport and type of boarding (boarding or deboarding). Across all airport locations, the average time to board an elevator is always longer than the average time to deboard an elevator.

4.3.3.1 Pre-Security Use Versus Post-Security Use

The location of the elevators relative to the security checkpoints affects use. Elevators located prior to security points will frequently carry passengers that have a higher number of bags. In contrast, post-security passengers often have less baggage. The reduction in baggage gives pas-

Table 4-11. Average elevator board times (in seconds) and passenger characteristics by airport.

Airport	ATL		DEN		DFW		MCO	
	B	D	B	D	B	D	B	D
Passengers	2.44	2.19	2.50	1.96	2.63	1.06	3.67	2.96
Boarding Time Duration (s)	10.04	7.10	9.61	6.71	8.58	3.94	11.01	7.73
Boarding Time Per Person (s)	4.12	3.24	3.85	3.43	3.27	3.71	3.00	2.61
Large Bags (#)	0.05	0.03	0.50	0.15	0.04	0.00	0.15	0.11
Backpack (#)	0.44	0.26	0.72	0.54	0.08	0.00	0.89	0.66
Roller (#)	0.62	0.57	1.33	1.21	0.21	0.25	1.84	1.33
Golf Bag (#)	0.00	0.00	0.08	0.03	0.00	0.13	0.03	0.01
Stroller (#)	0.30	0.22	0.09	0.07	0.13	0.19	0.17	0.15
Wheelchair (#)	0.50	0.44	0.04	0.03	0.00	0.00	0.05	0.05
Cart (#)	0.08	0.09	0.11	0.06	0.17	0.13	0.18	0.14

B – Boarding
D – Deboarding

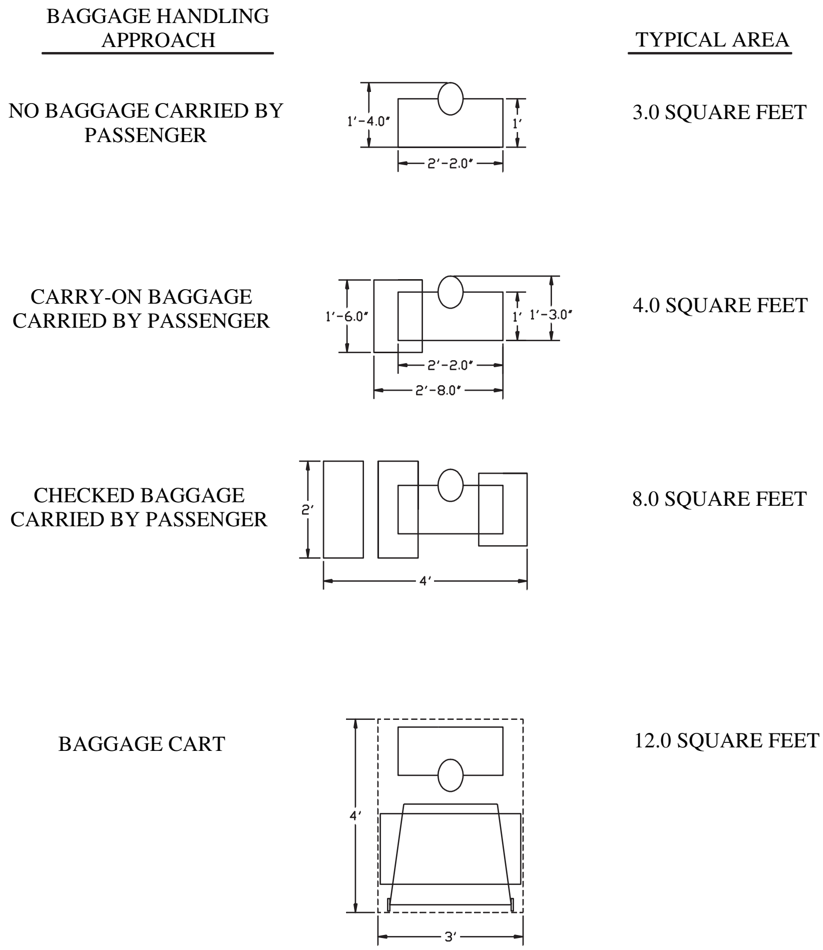


Figure 4-10. Typical area required for standee.

sengers additional alternatives in vertical conveyance choices. In addition, post-security passengers have a better understanding of available free time in relation to flight departure time. In those instances, passengers may select more leisurely passenger conveyance devices, that actually increase their walking distance, in order to use available retail or other airport services.

4.3.3.2 Area of Elevator

The amount of passenger baggage will directly affect the spacing available within elevator cabs. The elevators need to be sized to accommodate the passenger demands in relation to the anticipated baggage that will accompany those passengers.

4.3.3.3 Bags/Passenger

The amount of baggage an individual passenger has will increase the spacing requirements for that individual. Airport environments also increased space requirements for pedestrians because of baggage and the area required for the attendant baggage. A study at the Miami International Airport yielded the results for pedestrian space associated with additional baggage. Depending on the number of bags per person, the total space required varied from 4 to 9 sfpp. Figure 4-10 shows the typical area required for pedestrians with various forms of baggage, excluding maneuvering space.[1]

[1]Marlin Engineering. January 3, 1999-January 8, 1999 Curbfront Survey, Technical Memorandum, January 1999. Presented in Miami International Airport MIC/MIA Connector Baggage Transport Alternatives Study. Lea + Elliott. March 1999.

4.3.3.4 Passenger Equivalence

An important consideration in elevator conveyance systems is reviewing the space in the elevator cab based on passenger equivalence. Based on Figure 4-10, a passenger with no bags is 3.0 square feet. As discussed, maneuverability should also be considered.

4.3.3.5 Travel Time

One key consideration for elevators is travel time. The elevator travel time is a function of the elevator speed, number of floors served, and anticipated demands/calls between floors. If elevators are perceived to be slow, passengers may elect to use other modes of vertical conveyance unless restricted to elevators because of mobility concerns. The demands of traveling between floors should be evaluated to properly size the elevator with an appropriate speed.

4.3.4 Considerations for Stairs

4.3.4.1 Location

As indicated in Section 4.3.2, escalators are more often selected as the vertical passenger conveyance mode. However, when the demand of the escalators is exceeded and queues develop, passengers will often elect to use stairs if they are close by.

4.3.4.2 Rise Required

The rise required, coupled with the available spacing, will determine the vertical conveyance that can be incorporated. Escalators may require more area but can accommodate larger rise changes with less passenger discomfort. Using stairs to travel large rises could be difficult on passengers, especially passengers traveling with baggage.

4.3.5 Considerations for Moving Walkways

The data pertaining to moving walkways was analyzed to determine the average board rates as a function of airport and moving walkway tread-width, passenger horizontal conveyance mode as a function of airport, and average number of roller bags as a function of airports and passenger horizontal conveyance mode. Table 4-12 shows the average moving walkway board rates by airport and tread-width.

4.3.5.1 Distance Versus Demand

The distance to traverse directly affects the use of moving walkways. Passengers have a critical walking distance that they are willing to travel without the assistance of passenger conveyance devices. However, if the moving walkways are perceived as slow or are exceeding capacity, passengers may elect to walk, even long distances. Furthermore, depending on the available free time, passengers may also elect to walk longer distances, instead of using moving walkways, in order to access retail or other airport amenities.

Table 4-12. Moving walkway board rates (in persons per minute) by airport and width (in inches).

Airport	Board Rate (ppm)	Width (in)
ATL	57	40
CLT	52	40
DEN	56	60
DFW	33	38
MCO	67	48

CHAPTER 5

Passenger Conveyance Database and User's Guide

5.1 Obtaining the Database

The database is available on the accompanying CD-ROM and also can be downloaded from the TRB website as an ISO image and burned to a CD-ROM.

5.2 Background and System Requirements

To provide a comprehensive guide for evaluating passenger conveyance systems at airports, a database was designed and developed with information collected from the five airports. The database was created in Microsoft Office Access 2007/2010, a common database software package that many people can easily use. Microsoft Office Access is a member of the Microsoft Office suite applications. The following specifications are the system requirements for each software package as listed by Microsoft Corporation.

Microsoft Office Access 2007

(http://office.microsoft.com/en-us/products/2007-microsoft-office-release-system-requirements-HA010166865.aspx)

- Minimum processor, 500 megahertz (MHz) processor or higher.
- Memory, 512 megabyte (MB) RAM or higher.
- Hard disk, 2 gigabytes (GB); a portion of this disk space will be freed after installation if the original download package is removed from the hard drive.
- Display, 1024 × 768 or higher resolution monitor.
- Operating system, Microsoft Windows XP with Service Pack (SP) 2, Windows Server 2003 with SP1, or later operating system.

Microsoft Office Access 2010

(http://office.microsoft.com/en-us/products/microsoft-office-2010-system-requirements-HA101810407.aspx)

- Minimum processor: 500 megahertz (MHz) or faster processor.
- Memory: 256 MB RAM; 512 MB recommended for graphics features and certain advanced functionality.
- Hard disk: 3.0 gigabytes (GB) available disk space.
- Display: 1024x768 or higher resolution monitor.
- Operating system: Windows XP with Service Pack (SP) 3, Windows Server 2003 R2 with MSXML 6.0, (32-bit operating system (OS) only) or Windows Vista with SP1, Windows 7, Windows Server 2008, or later 32- or 64-bit OS.

5.3 ACRP Terminal Conveyances Database

The database allows users to view summary reports of vertical and horizontal conveyances at the study airports. The reports are presented by conveyance types—elevator, escalator, and moving walkway—and available for each transition area and across all transition areas. The database also provides a planning tool for vertical and horizontal transition considerations, as well as information concerning conveyance equipment. The following sections discuss the database functionalities and offer a basic user's guide.

Depending on the operating system being used, there are various methods for launching Microsoft Office 2007 or 2010. Using the Start Menu or Button, one can use the following path: Start → All Programs → Microsoft Office → Microsoft Office Access 2007 (or 2010).

Once Microsoft Office Access 2007 has been launched, search for the project database: "ACRP Pax Conveyance Database (03-14).mdb." Its location will depend on where you have chosen to store it on your computer. After using the database for the first time, you can then retrieve it by using the "Recent" or "Open Recent Database" command.

After opening the database, you will need to enable the active content because the database contains macro functions. In Access 2007, click the "Options" button, then click "Enable this content," and hit "OK" (see Figure 5-1). In Access 2010, you can directly "Enable this content" as shown in Figure 5-2.

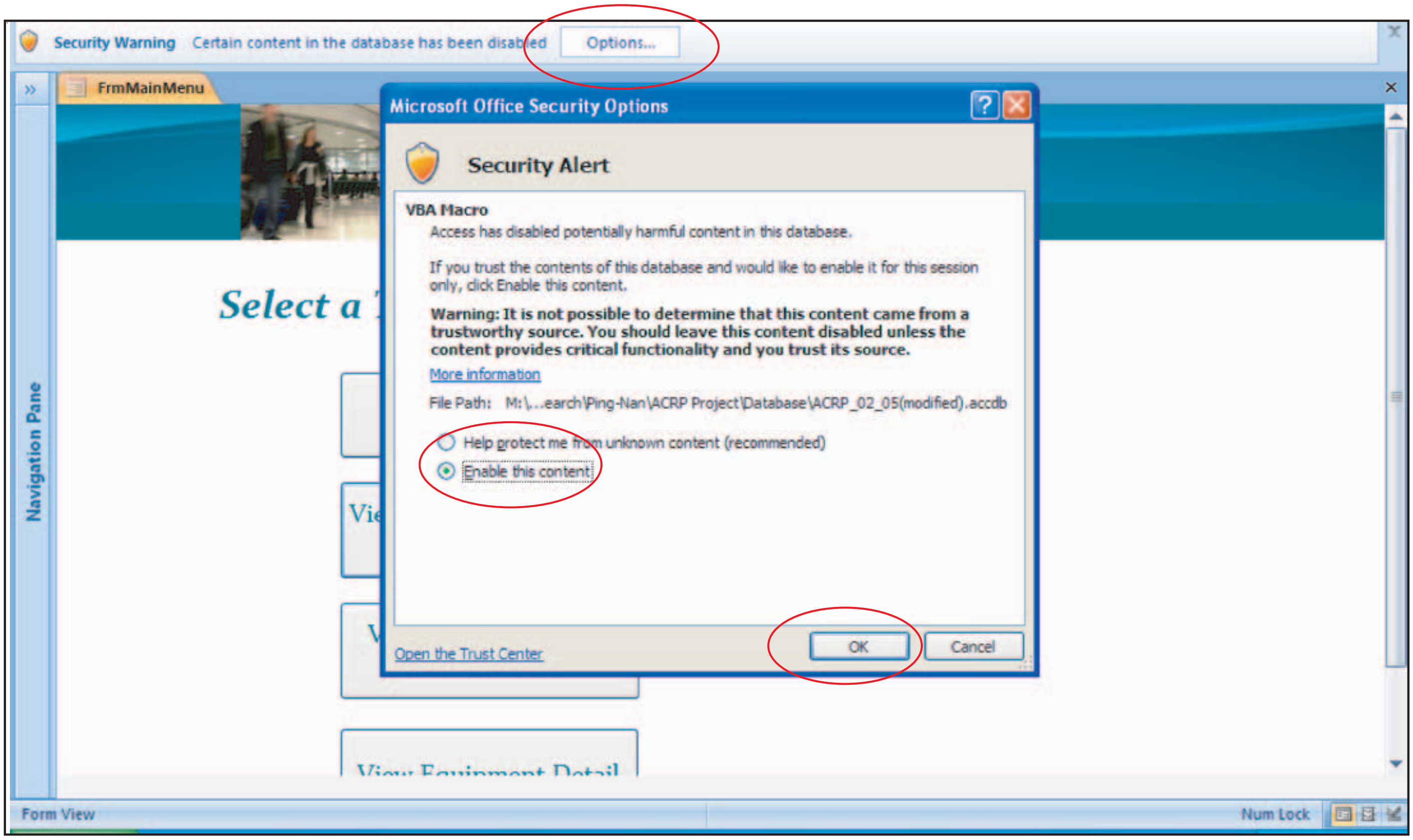


Figure 5-1. Enabling content—Access 2007.

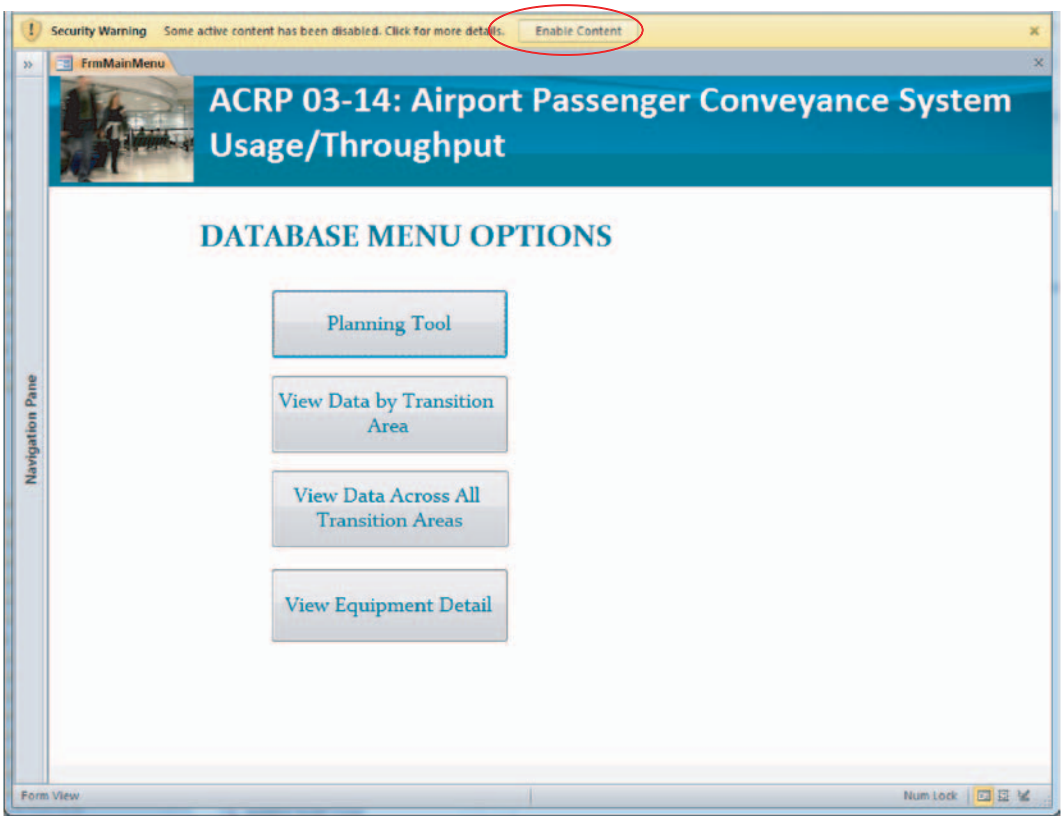


Figure 5-2. Enabling content—Access 2010.

5.3.1 Getting Started with the Database

The database allows users to view summary forms of vertical and horizontal conveyances at the study airports and serves as a planning tool for gauging transition equipment requirements when comparing a *planned* transition rate against *observed* transition rates and equipment performance at the five airports. The reports are presented by conveyance types—elevator, escalator, and moving walkway—and available for each transition area and across all transition areas.

The database starts from the Main Menu as shown in Figure 5-3. There are four options: Planning Tool, View Data by Transition Area, View Data Across all Transition Areas, and View Equipment Detail in the Main Screen.

5.4 Planning Tool

The planning tool is a decision-making framework to assist airport planners in deciding whether or not additional passenger conveyances are needed at the airport. Within the planning tool are two main categories: vertical transition analysis and horizontal transition analysis (each will be explained in greater detail in the following two subsections). We use an estimated 5-minute peak flow, along with information provided by the user that defines the particular transition area of interest, to display an "anticipated passenger per minute requirement" compared to the "passenger per minute throughput achieved in our data collection at a similar transition point." Based on the observations at the five airports, the research team believed it

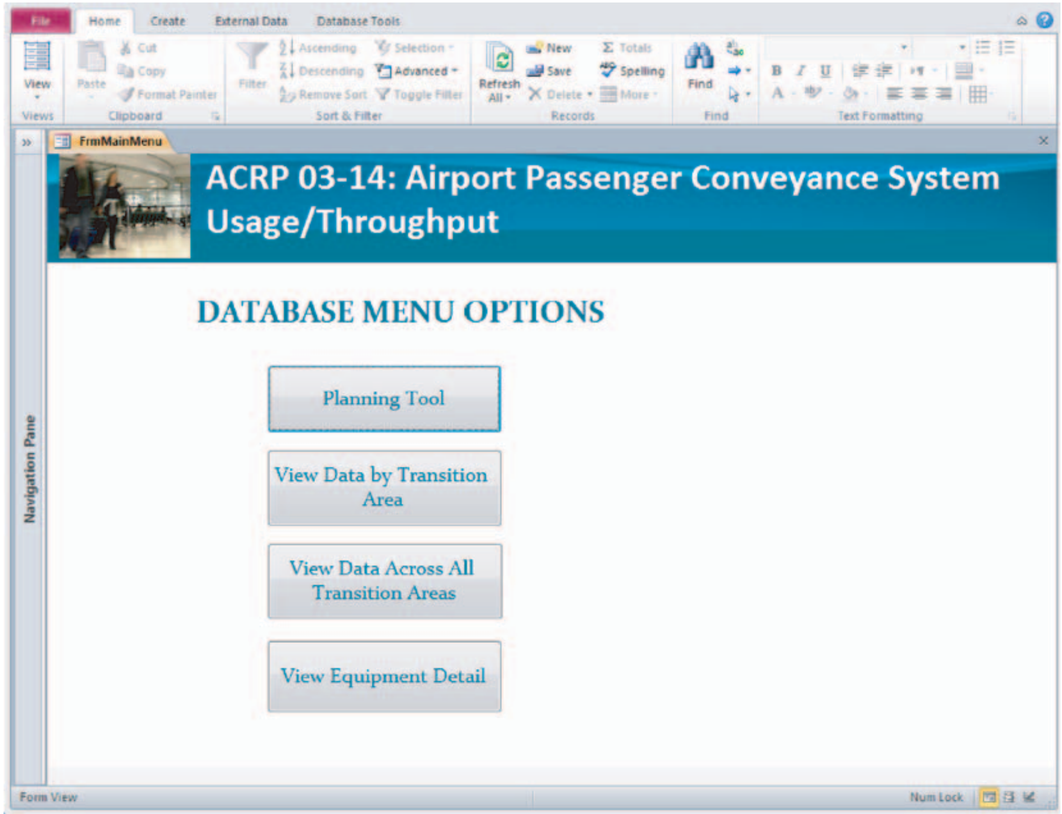


Figure 5-3. Main menu.

was not appropriate to suggest a specific transition equipment requirement, because this was highly dependent on airport and location within the airport. For this reason, the database tool allows the user to quickly see the observed performance at the other airports where equipment was installed in a location similar to their proposed area.

5.4.1 Vertical Transition Analysis

The following will take the user through the procedure for conducting a vertical transition analysis. The main planning tool screen is presented in Figure 5-4.

The user must perform the following steps:

1. Select a particular transition area of interest.
2. Include an estimate for the 1-minute or 5-minute passenger flow in this transition area.
3. Estimate the percent of passengers who will use elevators, stairs, and escalators (e.g., 5/15/80 with the total adding to 100).

If the user is unsure of the mode choice percentages to assign for a particular location, selecting the button 

will open a form that provides the mode choice percentages that were observed across the study airports for a similar location. Figure 5-5 illustrates this feature when Post-Security is selected as the area of interest.

After completing the above steps, the table "Observed Escalator Throughput" in the bottom right-hand corner provides the observed performance at other airports with one, two, and three

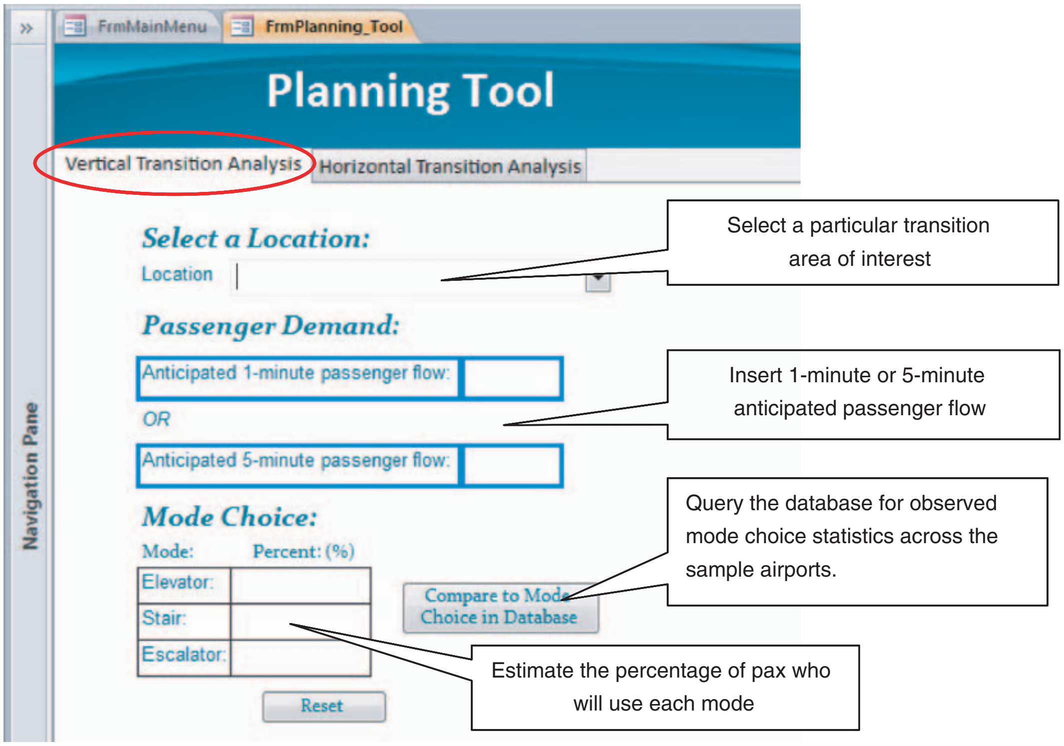


Figure 5-4. Planning tool-vertical transition analysis.

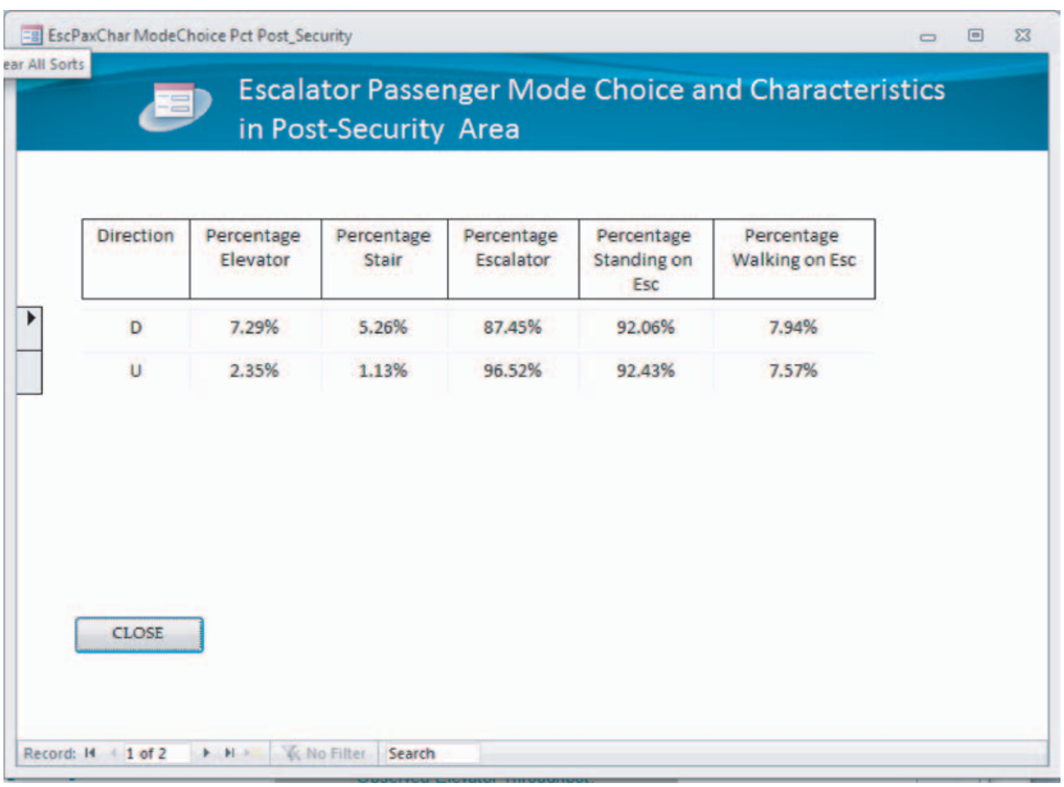


Figure 5-5. Mode choice percentages from the study airports.

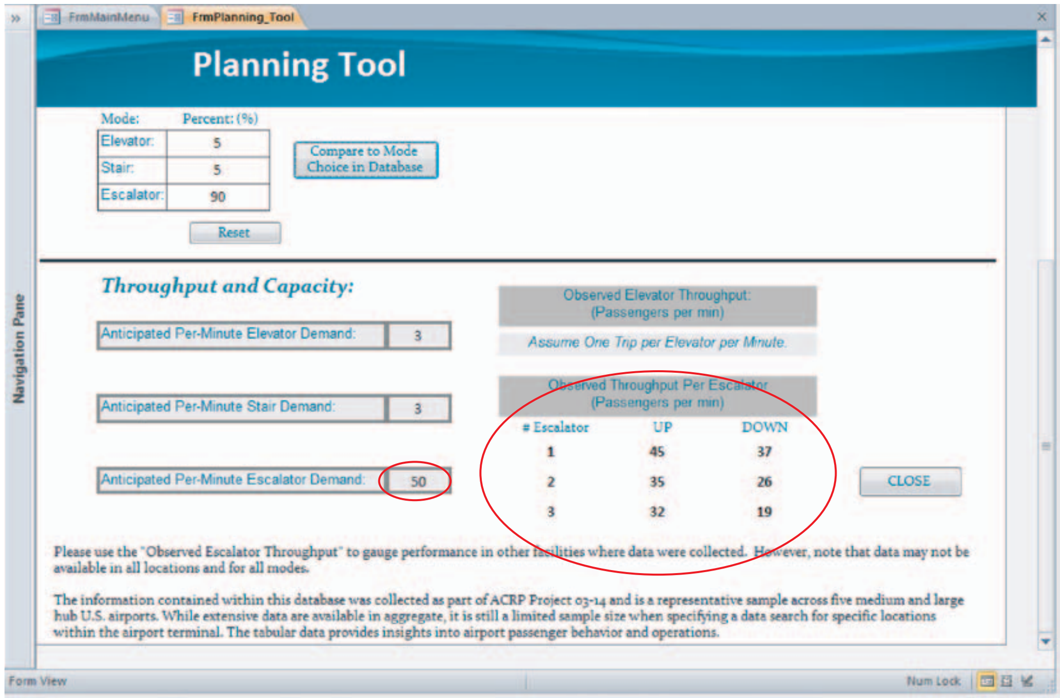


Figure 5-6. Observed performance by 1/2/3 escalators.

escalators installed in a similar area as shown in Figure 5-6. This provides the user with a comparison of actual performance against the anticipated peak 5-minute passenger flow for the area of study. Given the many factors that can contribute to actual escalator throughput, the research team concluded that it would not be justified to suggest a specific number of devices that would be able to handle the anticipated demand.

5.4.2 Horizontal Transition Analysis

The following will take the user through the procedure for conducting a horizontal transition analysis. The main planning tool screen is presented in Figure 5-7.

The user must perform the following steps:

1. Select a particular transition area of interest.
2. Include an estimate for a 1-minute or 5-minute passenger flow in this transition area.
3. Estimate the percent of passengers who will use/bypass moving walkways (e.g., 65/35).

The observed mode choice percentages at the five study airports within the specified location will automatically appear next to mode choice percentages just entered by the user (See Figure 5-8). These numbers can serve as a reference during the analysis.

After completing the above steps, the table "Observed Moving Walkway Throughput" in the bottom right-hand corner provides the observed performance at other airports with moving walkways installed in a similar area (See Figure 5-9). This provides the user with a comparison of actual performance against the anticipated peak 5-minute passenger flow for the area of study. Given the many factors that can contribute to actual escalator throughput, the research team concluded that it would not be justified to suggest a specific number of devices that would be able to handle the anticipated demand.

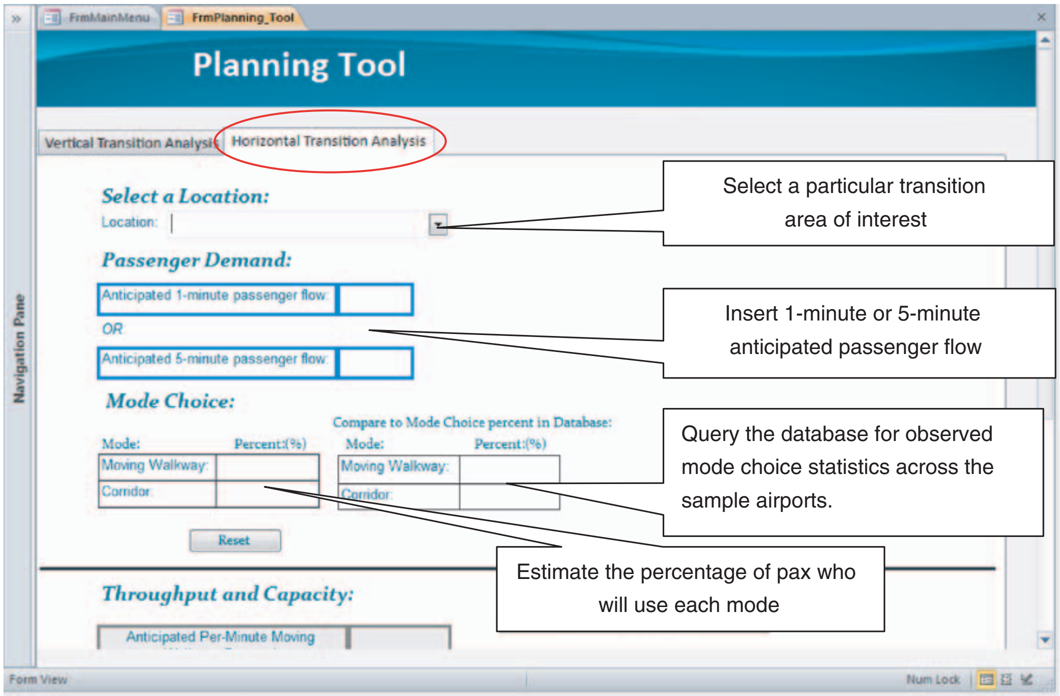


Figure 5-7. Planning tool-horizontal transition analysis.

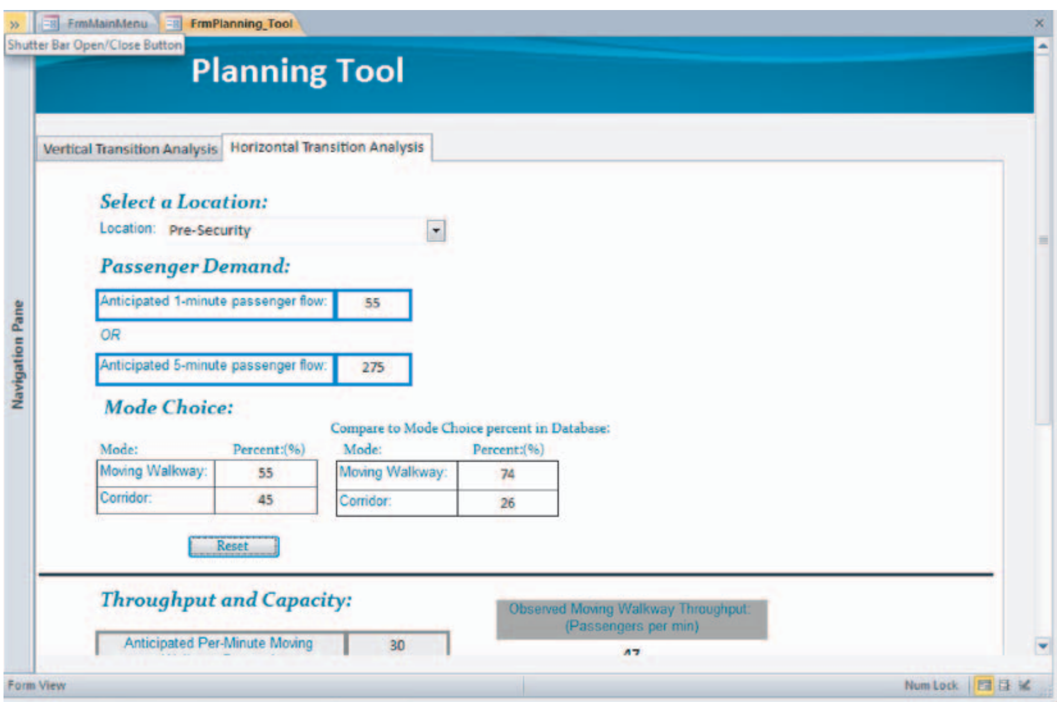


Figure 5-8. Mode choice from database.

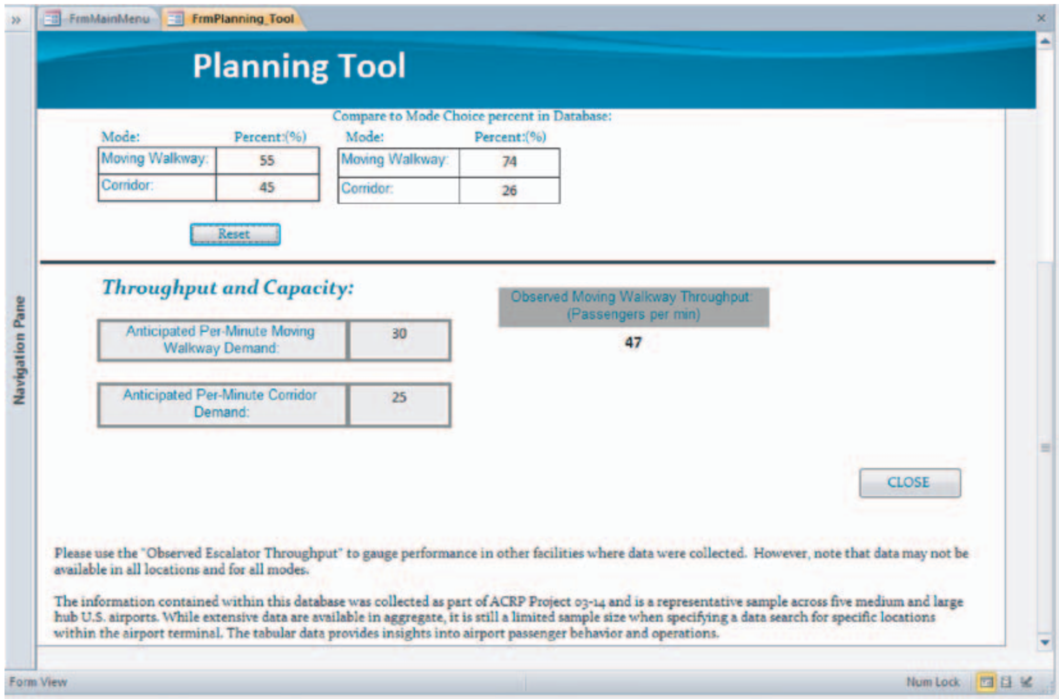


Figure 5-9. Moving walkway observed performance.

5.5 View Data by Transition Area

The function of "View Data by Transition Area" from the main screen is to allow the user to review the information of each subject by specific area within the airport. After clicking the button "View Data by Transition Area," the screen that follows (see Figure 5-10) will allow users to choose among several specific areas of interest. Data summary can be viewed

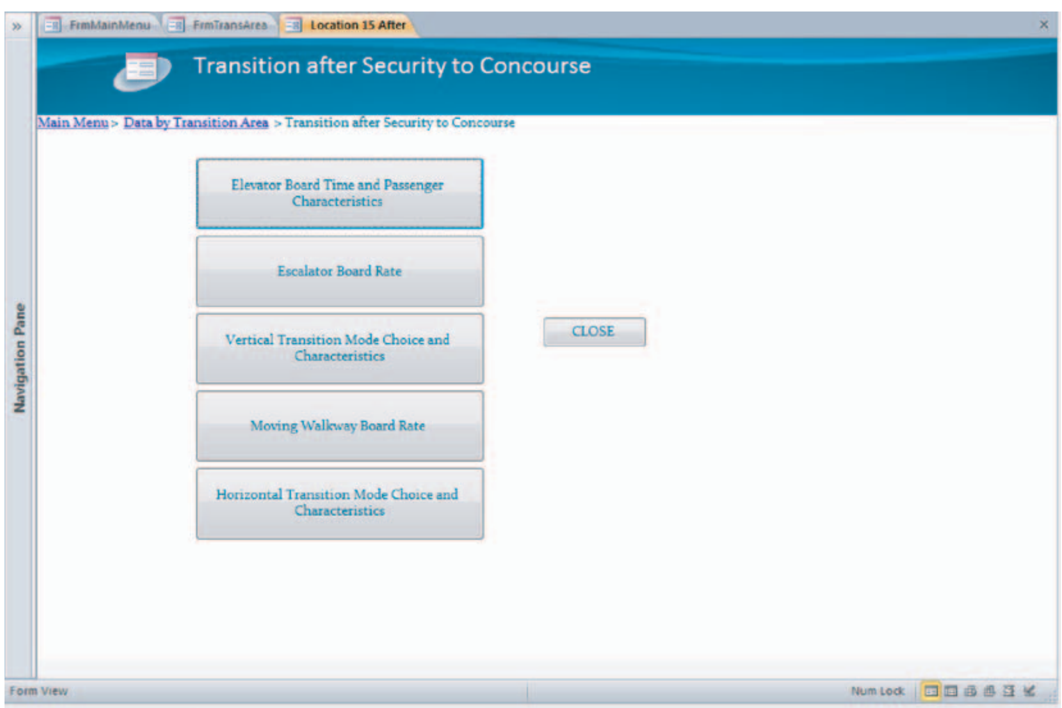


Figure 5-10. View data by transition area.

Figure 5-11. View data by transition area—in concourse.

at each of the 11 transition areas: parking and rental car, between parking/rental car and terminal, terminal to ticketing, ticketing to security, after security to concourse, after APM system, inside concourse, between concourses, inside terminal, terminal to baggage claim, after baggage claim.

Basic reports provided are shown below. Types of reports available at each transition area depend on the conveyance equipment used within the area, including the following statistics:

- Passenger mode choice and characteristics for vertical and horizontal conveyances
- Board rates for elevators, escalators, and moving walkways

For example, when considering "Transitions After Security to Concourse," Figure 5-11 indicates the available data analyses from which you can select.

5.6 View Data Across All Transition Areas

Users can review the data information across all transition areas by using this function. After clicking the "View Data Across All Transition Areas" button from the Main Menu, the screen in Figure 5-12 indicates how users can choose among several specific measurements (e.g., board rate, passenger characteristics, and mode choices). Reports are categorized by conveyance type—elevator, escalator, and moving walkway.

5.6.1 Elevators

Observations were collected for elevator-specific operations. The summarized data includes information specific to elevator boarding and deboarding trips, as well as many characteristics about the passengers traveling on those trips. They are reported in three different views: by airport, by door open width, and by airport and door open width, as shown in Figure 5-13. A sample form by airport is shown in Figure 5-14. A summarized report of the elevator board time and passenger characteristics by airport is provided in Chapter 4.

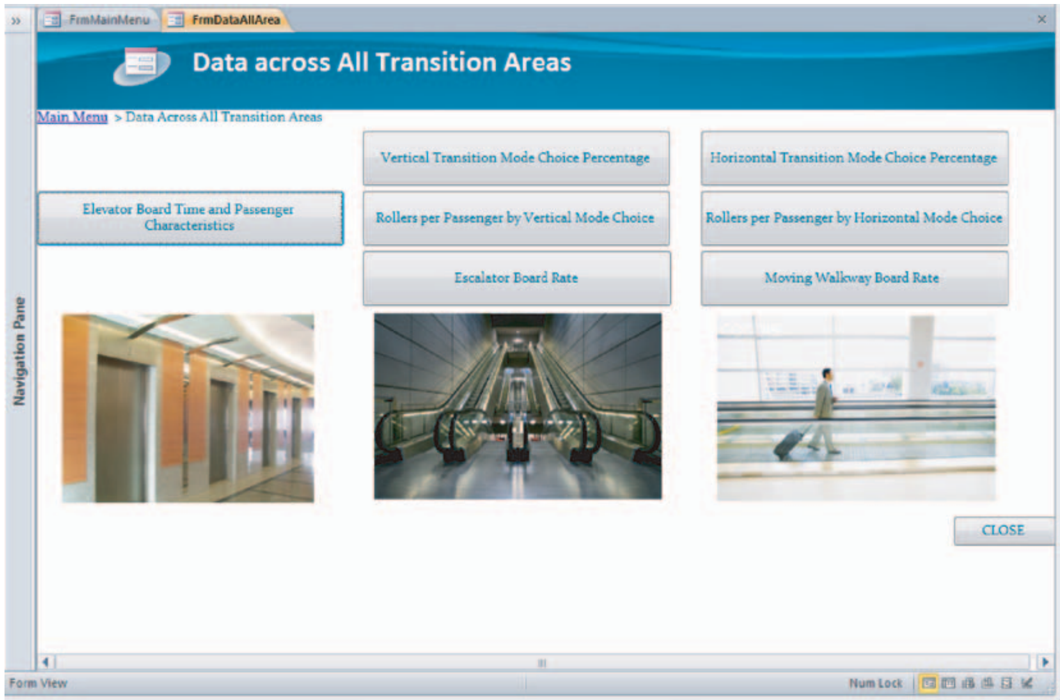


Figure 5-12. View data across all transition areas.

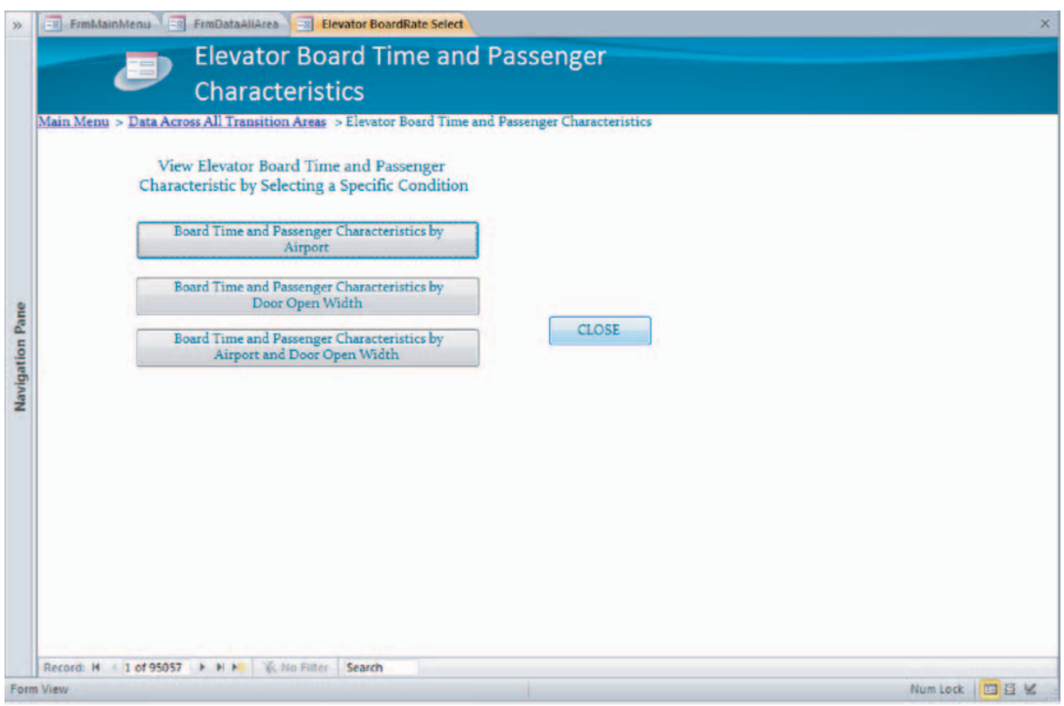
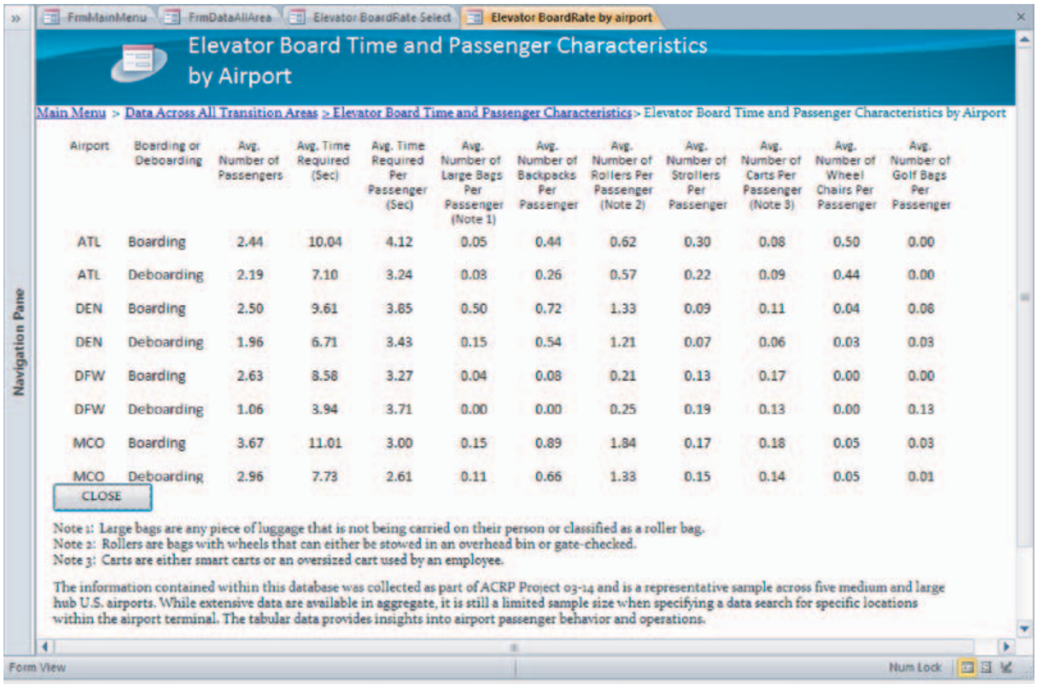


Figure 5-13. Elevator board time and passenger characteristics.



FrmMainMenu | FrmDataAllArea | Elevator BoardRate Select | Elevator BoardRate by airport

Elevator Board Time and Passenger Characteristics by Airport

Main Menu > Data Across All Transition Areas > Elevator Board Time and Passenger Characteristics > Elevator Board Time and Passenger Characteristics by Airport

Airport	Boarding or Deboarding	Avg. Number of Passengers	Avg. Time Required (Sec)	Avg. Time Required Per Passenger (Sec)	Avg. Number of Large Bags Per Passenger (Note 1)	Avg. Number of Backpacks Per Passenger	Avg. Number of Rollers Per Passenger (Note 2)	Avg. Number of Strollers Per Passenger	Avg. Number of Carts Per Passenger (Note 3)	Avg. Number of Wheel Chairs Per Passenger	Avg. Number of Golf Bags Per Passenger
ATL	Boarding	2.44	10.04	4.12	0.05	0.44	0.62	0.30	0.08	0.50	0.00
ATL	Deboarding	2.19	7.10	3.24	0.03	0.26	0.57	0.22	0.09	0.44	0.00
DEN	Boarding	2.50	9.61	3.85	0.50	0.72	1.33	0.09	0.11	0.04	0.08
DEN	Deboarding	1.96	6.71	3.43	0.15	0.54	1.21	0.07	0.06	0.03	0.03
DFW	Boarding	2.63	8.58	3.27	0.04	0.08	0.21	0.13	0.17	0.00	0.00
DFW	Deboarding	1.06	3.94	3.71	0.00	0.00	0.25	0.19	0.13	0.00	0.13
MCO	Boarding	3.67	11.01	3.00	0.15	0.89	1.84	0.17	0.18	0.05	0.03
MCO	Deboarding	2.96	7.73	2.61	0.11	0.66	1.33	0.15	0.14	0.05	0.01

CLOSE

Note 1: Large bags are any piece of luggage that is not being carried on their person or classified as a roller bag.
Note 2: Rollers are bags with wheels that can either be stowed in an overhead bin or gate-checked.
Note 3: Carts are either smart carts or an oversized cart used by an employee.

The information contained within this database was collected as part of ACRP Project 03-14 and is a representative sample across five medium and large hub U.S. airports. While extensive data are available in aggregate, it is still a limited sample size when specifying a data search for specific locations within the airport terminal. The tabular data provides insights into airport passenger behavior and operations.

Navigation Pane

Form View

Num Lock

Figure 5-14. Elevator board time and passenger characteristics—by airport.

5.6.2 Escalators

There are eight forms for escalator board rates as shown in Figure 5-15. These forms are presented in varied perspectives (e.g., by airport, direction, width, number of escalator, and combinations of these factors). Figure 5-16 shows a sample form for board rates by airport.

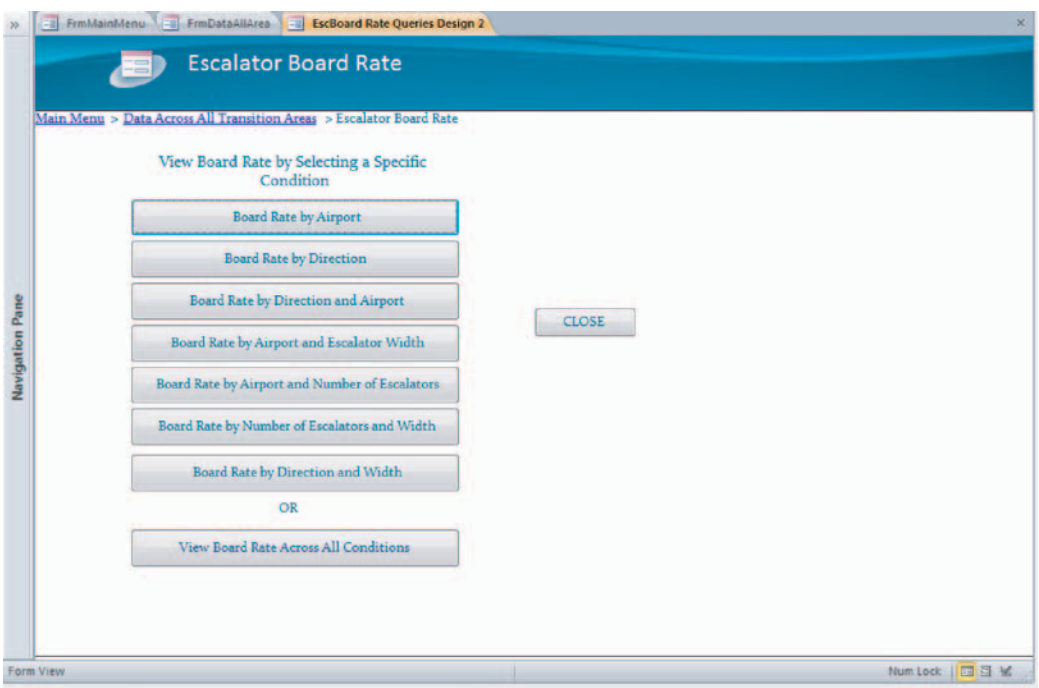


Figure 5-15. Escalator board rate options.

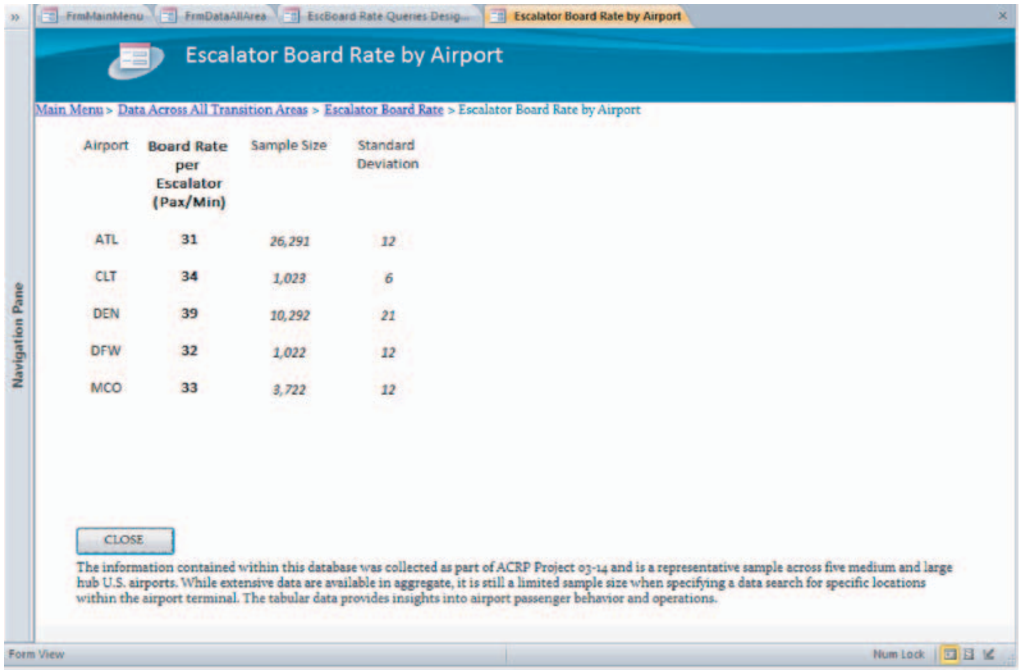


Figure 5-16. Escalator board rate—by airport.

The vertical transition mode choice percentage forms provide percentage of passengers using stairs, elevators, escalators, escalator and walk, or escalator and stand. The forms are also offered by airport and travel direction as shown in Figure 5-17. Figure 5-18 then shows a sample form for vertical transition passenger characteristics by direction.

Finally, the average number of roller bags per passenger is calculated by all vertical transition mode choices. Figure 5-19 shows how the information is presented in the database.

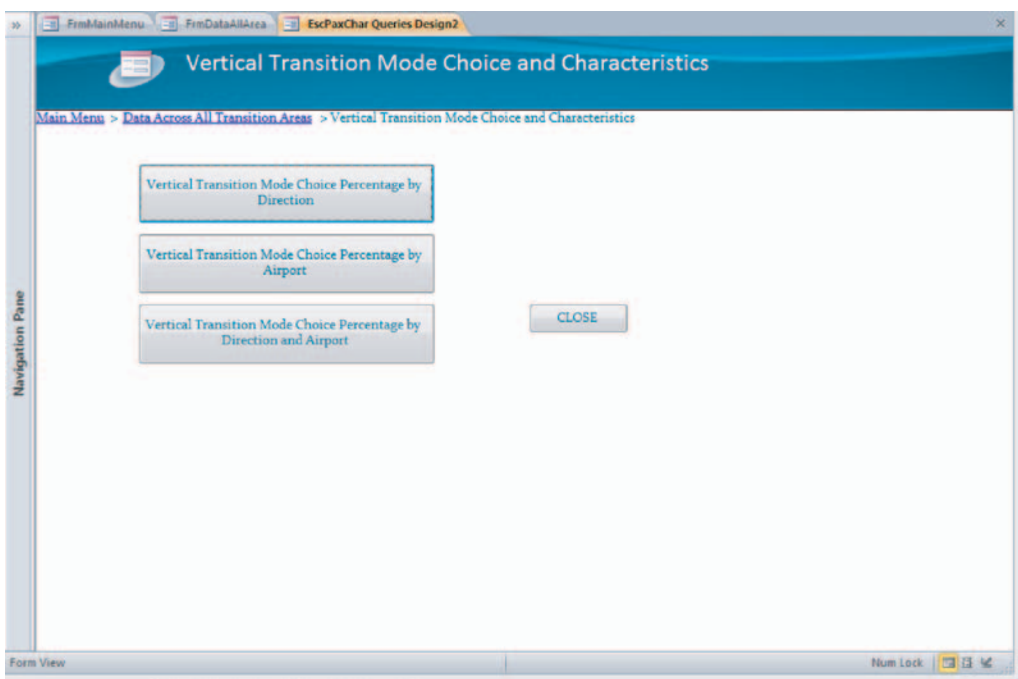


Figure 5-17. Vertical transition mode choice options.

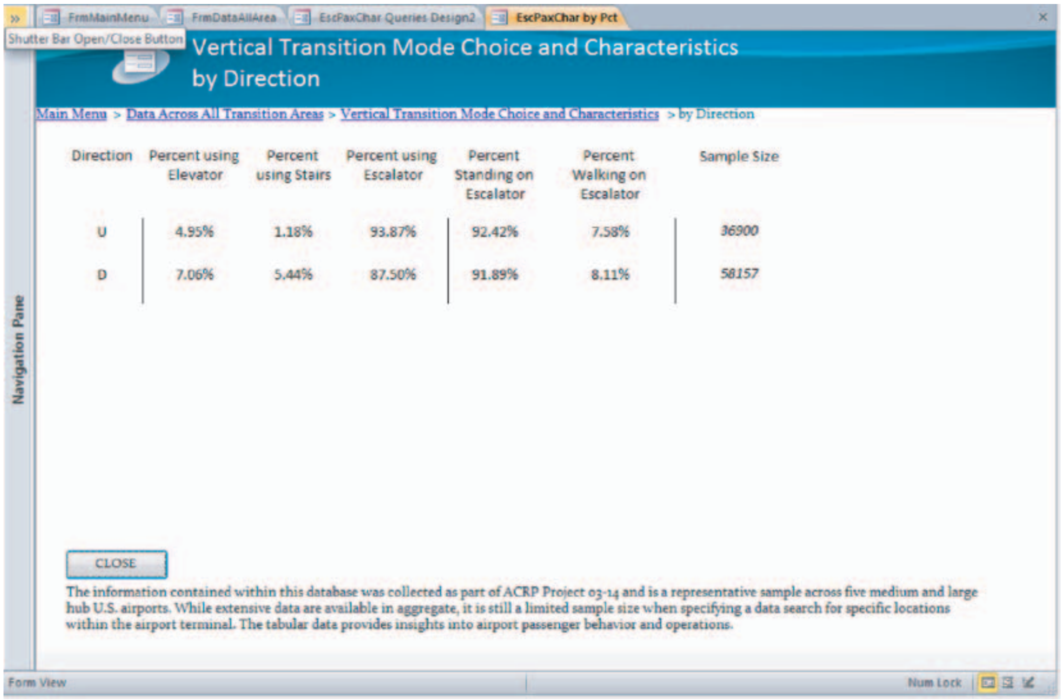


Figure 5-18. Escalator mode choice options—by direction.

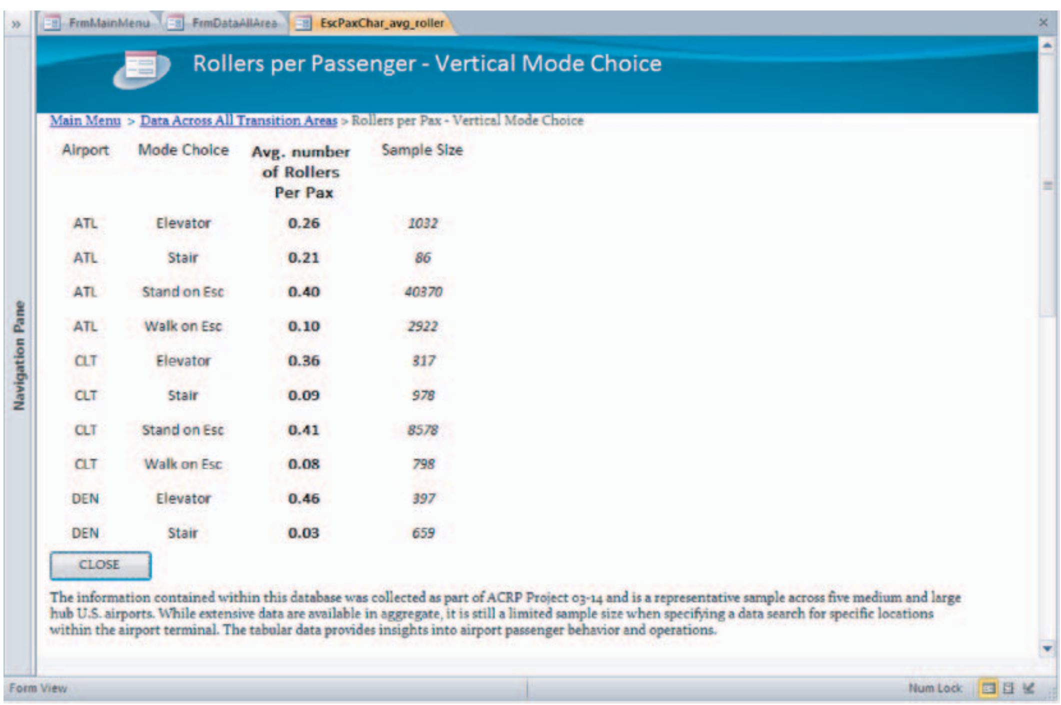


Figure 5-19. Number of rollers per passenger—vertical mode choice options.

Sample reports of the escalator board rate, passenger mode choice characteristics, and roller bags per passenger are also provided in Chapter 4.

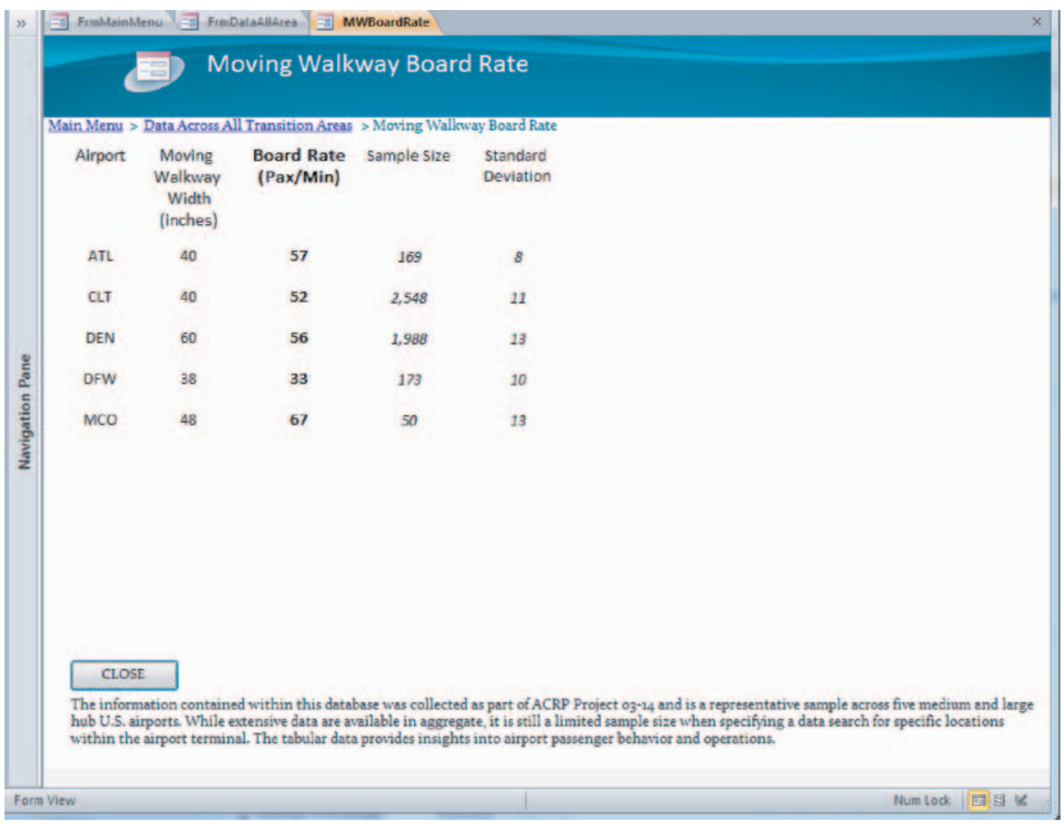
5.6.3 Moving Walkways

Three reports/forms are available for moving walkways: (1) moving walkway board rate, (2) horizontal mode choice, which provides the percentage of passengers using the corridor or moving walkway, as well as whether a passenger chooses to walk or stand once on the moving walkway; and (3) average number of roller bags for each horizontal mode choice.

The moving walkway board rates are displayed in Figure 5-20. The moving walkway widths for each airport are also included.

The horizontal mode choice data provides the percentage of passengers using the moving walkways and the percentage of passengers using the corridor (and bypassing the walkways). Moving walkway use is further broken down by those standing and those walking. The form is presented in Figure 5-21. Finally, the average number of roller bags per passenger is calculated by all horizontal transition mode choices. Figure 5-22 shows how the information is presented in the database.

Sample reports of the board rates, passenger mode choice characteristics, and roller bags per passenger are also provided in Chapter 4.



FrmMainMenu FrmDataAllArea MWBoardRate

Moving Walkway Board Rate

Main Menu > Data Across All Transition Areas > Moving Walkway Board Rate

Airport	Moving Walkway Width (inches)	Board Rate (Pax/Min)	Sample Size	Standard Deviation
ATL	40	57	169	8
CLT	40	52	2,548	11
DEN	60	56	1,988	13
DFW	38	33	173	10
MCO	48	67	50	13

CLOSE

The information contained within this database was collected as part of ACRP Project 03-14 and is a representative sample across five medium and large hub U.S. airports. While extensive data are available in aggregate, it is still a limited sample size when specifying a data search for specific locations within the airport terminal. The tabular data provides insights into airport passenger behavior and operations.

Navigation Pane

Form View Num Lock

Figure 5-20. Moving walkway board rates.

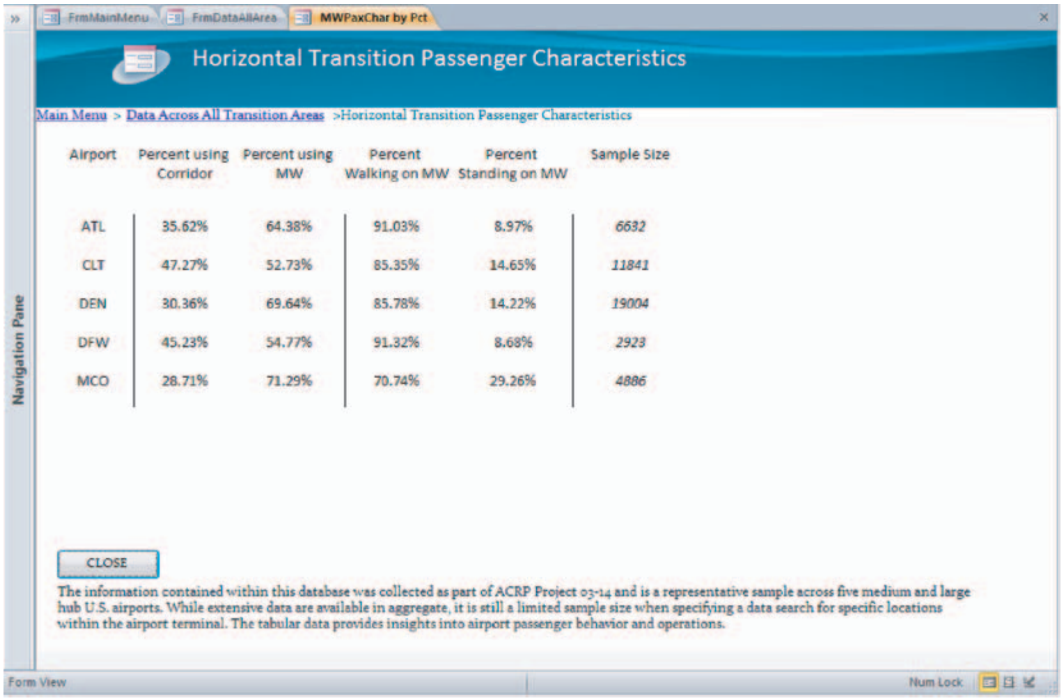


Figure 5-21. Horizontal transition passenger characteristics.

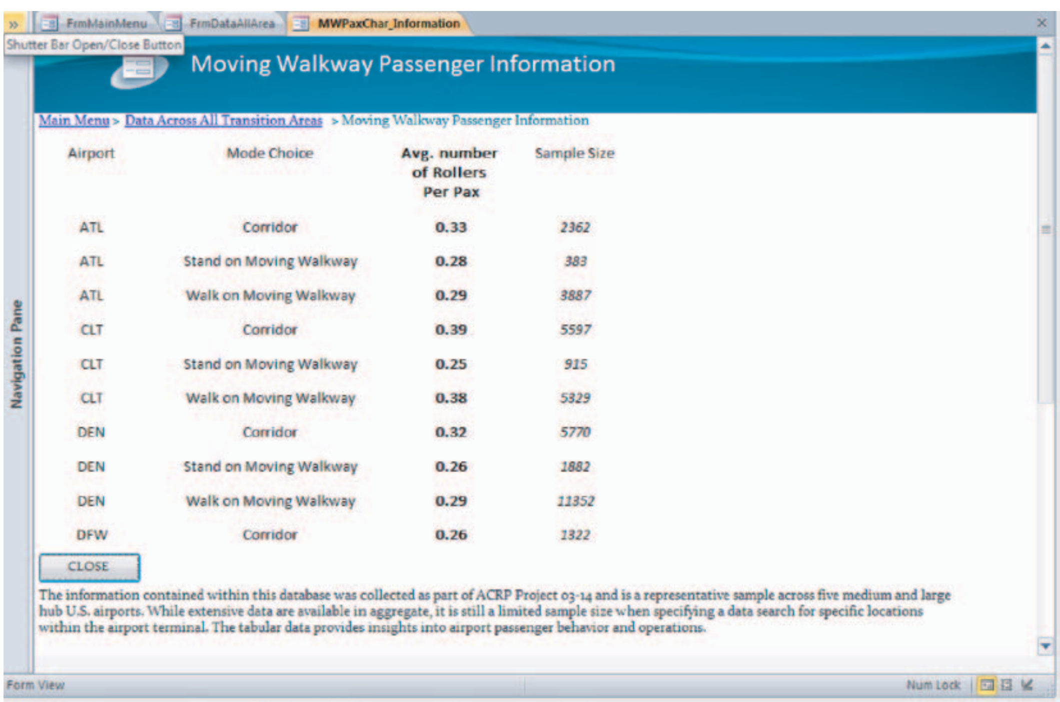


Figure 5-22. Number of rollers per passenger—horizontal mode choice options.

5.7 View Equipment Detail

In addition to information about the use of conveyance devices in airports, this database also provides device manufacturers and physical characteristics of devices (e.g., speed, length, and width) for which information was available. The user can review each type of equipment within this section of the database. After clicking the button "View Equipment Detail" in the Main Menu, the following screen (Figure 5-23) provides four types of conveyance devices: Elevator, Moving Walkway, Escalator, and Wheel Chair Lift for users to review.

Detailed information for elevators includes manufacturer, model, lower/upper capacity, lower/upper maximum speed, maximum number of stops, and lower/upper maximum rise, as displayed in Figure 5-24. Escalator information includes manufacturer, model, maximum

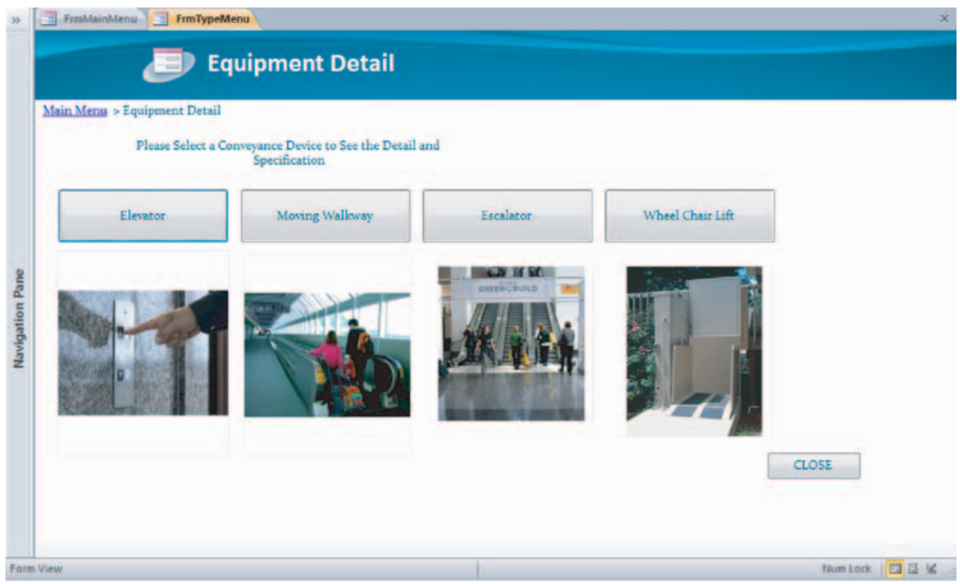


Figure 5-23. View equipment detail.

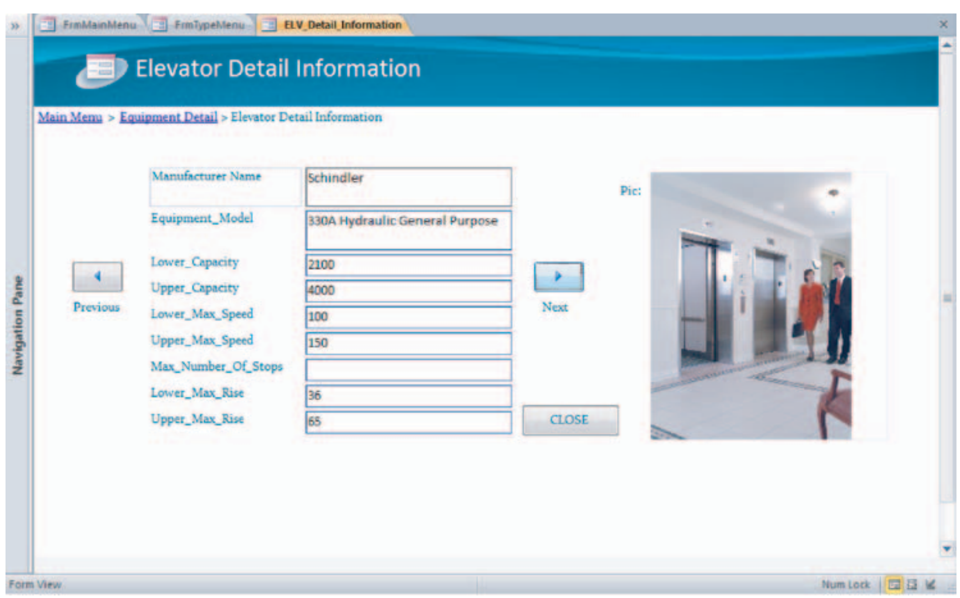


Figure 5-24. Elevator detailed information.

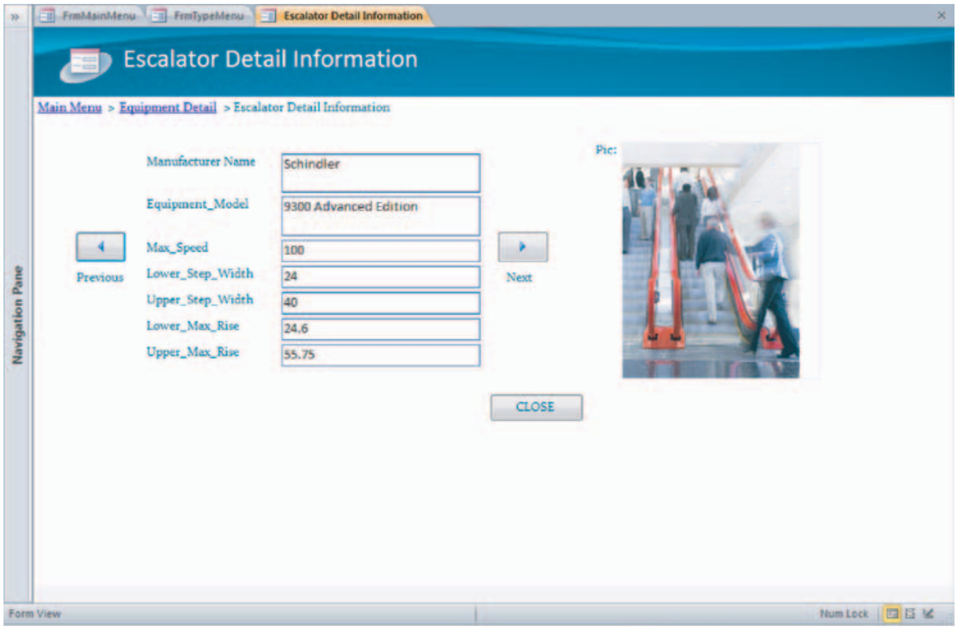


Figure 5-25. Escalator detailed information.

speed, lower/upper step width, and lower/upper maximum rise. Figure 5-25 shows an example of escalator information. Moving walkway information includes manufacturer, model, lower/upper maximum speed, lower/upper pallet width, maximum length, and lower/upper maximum angle. An example of moving walkway information is shown in Figure 5-26. Wheelchair lift information includes manufacturer, model, lower/upper capacity, lower/upper platform area, lower/upper maximum speed, lower/upper maximum stops, and maximum rise. Figure 5-27 shows the wheelchair lift information and picture.

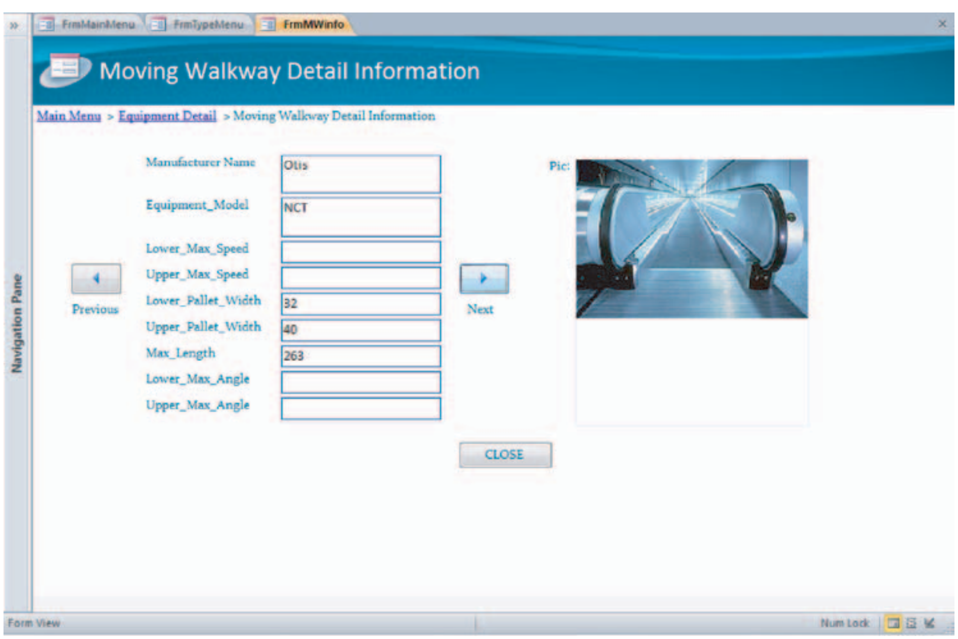


Figure 5-26. Moving walkway detailed information.

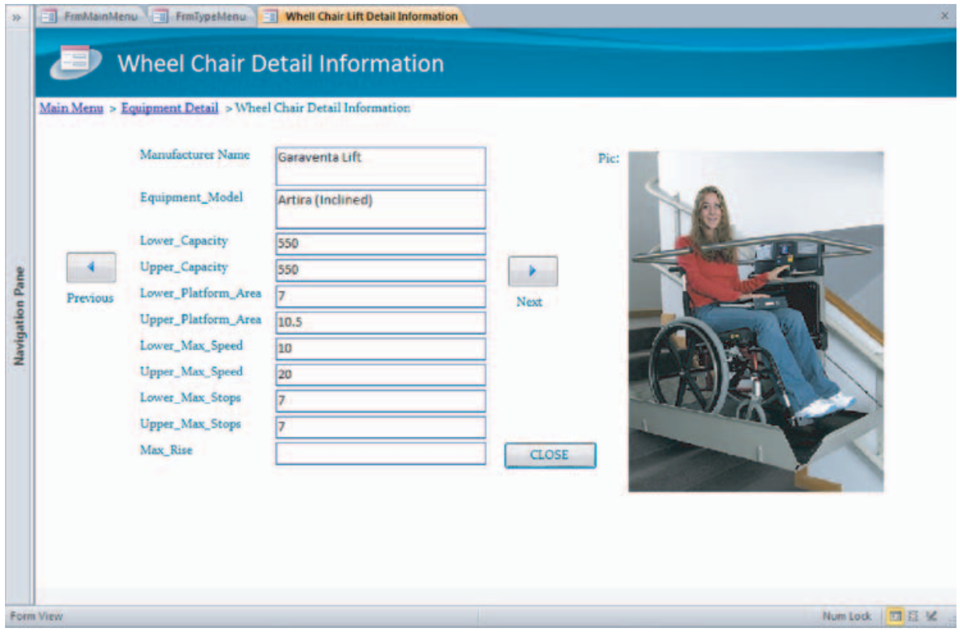


Figure 5-27. Wheelchair lift detailed information.

References

Lea + Elliott et al. 2010, *ACRP Report 37: Guidebook for Planning and Implementing Automated People Mover Systems at Airports,* Transportation Research Board. National Academy of Sciences, Washington, DC.

Ashford, N., et al. 1996, *Airport Operations,* 2nd edn, McGraw-Hill Professional.

Bandara, S. and Wirasinghe, S. C. 1986, "Parameters of Moving Sidewalks for Airport Terminal Pier Fingers," *Transportation Planning and Technology,* vol. 11, no. 2.

Bandara, J. M. S. J. 1989, *Airport Terminals-Optimum Configurations and Gate Position Requirement,* University of Calgary (Canada).

Barney, G. C. 2003, *Elevator Traffic Handbook: Theory and Practice,* Spon Press.

Davis, P. and Dutta, G. 2002, *Estimation of Capacity of Escalators in London Underground.*

Dempsey, P. S. 2000, *Airport Planning and Development Handbook: A Global Survey,* McGraw-Hill.

de Neufville, R., et al. 2002, "Optimal Configuration of Airport Passenger Buildings for Travelers," *Journal of Transportation Engineering,* vol. 128, no. 3, pp. 211–217.

Delve, D. 2004, "Up, Down- and Along Moving the Passenger," *Airports International Magazine,* vol. 37, no. 1, pp. 26–27.

FAA 1994, *Advisory Circular 150/5360-13 Planning and Design Guidelines for Airport Terminal Facilities,* Federal Aviation Administration, Washington, DC.

Fruin, J. J. 1971, *Pedestrian Planning and Design,* Elevator World, Inc.

Helbing, D. 1991, "A Mathematical Model for the Behaviour of Pedestrians," *Behavioral Science,* vol. 36, no. 4, pp. 298.

Horonjeff, R. and Hoch, C. J. 1975, "Some Facts About Horizontal Moving Sidewalk at Airports," Publication of American Society of Civil Engineers, p. 323–334.

Horonjeff, R., et al. 2010, *Planning and Design of Airports,* 5th edn, McGraw-Hill.

Hui, X., et al. 2007, "Pedestrian Walking Speed, Step Size, and Step Frequency from the Perspective of Gender and Age: Case Study in Beijing, China."

International Air Transport Association 2004, *Airport Development Reference Manual,* 9th edn, Montreal-Geneva.

JKH Mobility Services. DCA New Terminal Project, Analysis of Baggage Cart and Vertical Circulation Requirements, February 12, 1992.

Joy, J. E. 2001, "Non-Secure Inter-Terminal Passenger Conveyance Alternatives for George Bush Intercontinental Airport/Houston," *International Conference on Automated People Movers.*

Kyle, R. G. 1998, "Washington Dulles International Airport Passenger Conveyance Study," pp. 1119.

Leder, W. H. 1991, "Review of Four Alternative Airport Terminal Passenger Mobility Systems," *Transportation Research Record 1308,* pp. 134–141. Transportation Research Board, National Academy of Sciences, Washington, DC.

Marlin Engineering. January 3, 1999-January 8, 1999 Curbfront Survey, Technical Memorandum, January 1999. Presented in Miami International Airport MIC/MIA Connector Baggage Transport Alternatives Study. Lea + Elliott. March 1999

Odoni, A. R. and de Neufville, R. 1992, "Passenger Terminal Design," *Transportation Research, Part A: General,* vol. 26A, no. 1, pp. 27–35.

Omer, K. F. and Khan, A. M. 1988, "Airport Landside Level of Service Estimation: Utility Theoretic Approach," *Transportation Research Record 1199,* pp. 33–40. Transportation Research Board, National Academy of Sciences, Washington, DC.

O'Neil, R. S. 1974, "Escalators in Rapid Transit Stations," *Journal of the Transportation Engineering Division,* vol. 100, no. 1, pp. 1–12.

Pfurr, A. 2006, “Moving into the Future,” *Airports International,* vol. 39, no. 1, pp. 36–37.

Pushkarev, B. and Zupan, J. M. 1975, *Urban Space for Pedestrians,* The MIT Press, Cambridge, Mass.

Russell, H. 2004, “Up in the air: Gatwick gets passenger moving,” *Bridge Design and Engineering,* no. 37, pp. 34–36.

Seneviratne, P. N. 1985, “Acceptable Walking Distances in Central Areas,” *Journal of Transportation Engineering,* vol. 111, no. 4, pp. 365–276.

Seneviratne, P. N. and Morrall, J. F. 1985, “Level of service on pedestrian facilities,” *Transportation Quarterly,* vol. 39, no. 1, pp. 109–123.

Seneviratne, P. N. and Wirasinghe, S. C. 1989, “On the Optimal Width of Pedestrian Corridors,” *Transportation Planning and Technology,* vol. 13, pp. 195–203.

Smith, M. S. and Butcher, T. A. 2008, “How Far Should Parkers Have to Walk?” *Parking,* vol. 47, no. 4.

Srinivasan, M. 2009, “Optimal Speeds for Walking and Running, and Walking on a Moving Walkway,” American Institute of Physics, *CHAOS,* vol. 19.

The Ralph M. Parsons Company 1975, *The Apron and Terminal Building Planning Manual.*

Young, S. B. 1995, “Analysis of Moving Walkway Use in Airport Terminal Corridors,” *Transportation Research Record 1506,* pp. 44–51. Transportation Research Board, National Academy of Sciences, Washington, DC.

Young, S. B. 1999, “Evaluation of Pedestrian Walking Speed in Airport Terminals,” *Transportation Research Record 1674,* pp. 20–26. Transportation Research Board, National Academy of Sciences, Washington, DC.

Zacharias, J. 2001, “Pedestrian Behavior and Perception in Urban Walking Environments,” *Journal of Planning Literature,* vol. 16, no. 3.

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation